Oceanus

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Is the Arctic feeling the heat? PAGES 24-32

Doing the right thing for the right whale PAGES 16-21

A mysterious plague kills Northeast clams PAGE 22

WOODS HOLE OCEANOGRAPHIC INSTITUTION
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75 Years of Exploration

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THROUGH THE LENS

◄ A party of scientists and crew returns to ship after installing an Ice-Tethered Profiler on an Arctic Ocean ice floe in August 2005. The device dangles instruments into a hole in the ice and transmits ocean measurements daily via satellite to scientists on land. WHOI engineer John Kemp hauls the equipment sled; WHOI researcher Rick Krishfield brings up the rear.

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RESEARCH NEWS

OCEAN POLICY

OCEAN TECHNOLOGY

STUDENTS AT WORK

WHOI AROUND THE WORLD

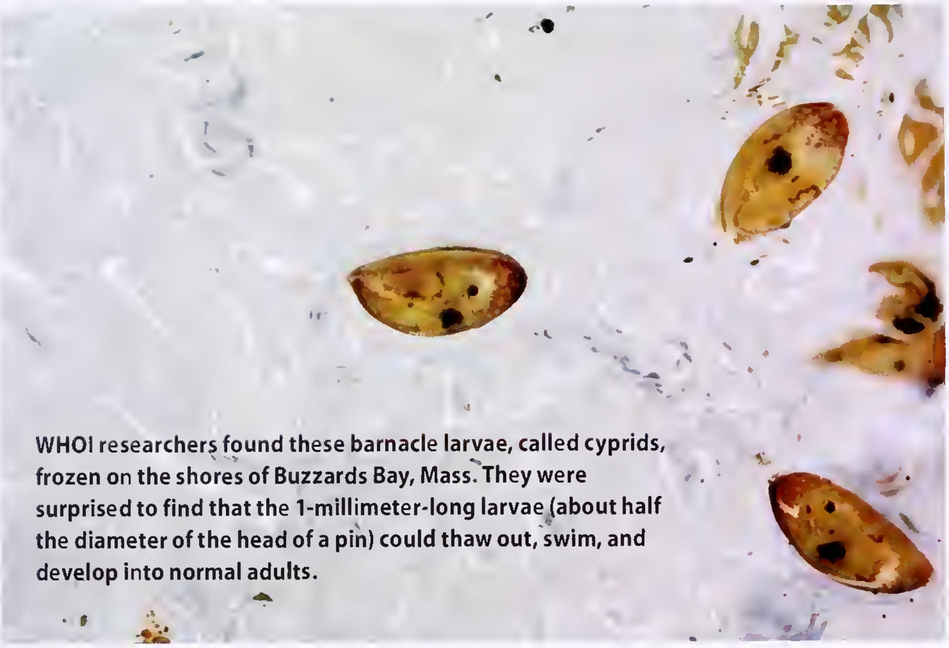
AROUND WHOI

A CONVERSATION WITH..

COVER: John Kemp, a WHOI engineer, is lowered by basket from an icebreaker to hook a tangled chain of yellow floats—the bottom end of a mooring (the top end surfaced somewhere under a jumble of sea ice). Instruments on the mooring collected data for a year to explore changing conditions in the Arctic Ocean (see stories, pages 24-32).
Photo by Chris Linder, WHOI

FEATURES

Regina Campbell-Malone, WHOI



WHOI researchers found these barnacle larvae, called cyprids, frozen on the shores of Buzzards Bay, Mass. They were surprised to find that the 1-millimeter-long larvae (about half the diameter of the head of a pin) could thaw out, swim, and develop into normal adults.

Jesús Pineda, WHOI

Barnacle larvae can survive and thrive after big chill

Cast adrift in coastal oceans, the tiny, weakly swimming larvae of marine animals such as barnacles employ the ocean's currents and tides—and avoid obstacles and predators—to arrive at a place where they can mature into adults. Ice was always thought to be one of those obstacles, and a larva that didn't settle down before winter set in was considered a goner.

But in the winter of 2003, Claudio DiBacco, a postdoctoral investigator, and Research Associate Vicke Starczak, both working with WHOI marine ecologist Jesús Pineda, were taking samples of seawater along the Rhode Island shore and found barnacle larvae frozen into sea ice. They placed them in water, where the larvae revived and swam normally.

▲ Carolina Cartes, a visiting investigator from Chile working with WHOI biologist Jesús Pineda, looks for tiny larval barnacles in icy intertidal zones.

The intriguing finding detoured Pineda's lab group into a new series of lab and field experiments. He and colleagues (some from the warm climates of Spain and Chile) and two local high school students worked in icy conditions from January to May tracking thousands of larvae in coastal sites from Rhode Island to Nova Scotia. In the September 2005 issue of the journal *Limnology and Oceanography*, the team reported that barnacle larvae can remain frozen up to seven weeks and still revive, settle, and grow to reproduce.

"We tend to have an anthropocentric view of larvae as babies that don't tolerate severe conditions," Pineda said, "but it isn't always true."

The discovery offers a new understanding of barnacle larvae, which are abundant sources of food for larger animals in the coastal ocean. It also provides possible clues to how other northern intertidal marine invertebrates may settle and survive harsh winters.

—*Kate Madin*

This research was funded by the National Science Foundation.

Alvin comes home for an overhaul

A new robotic arm is just one of the upgrades expected for the submersible *Alvin* when it gets its periodic tune-up this winter.

During the sub's six-month overhaul, which comes after 511 dives to the seafloor since 2001, "literally every component will be taken apart for cleaning and examination," said pilot Pat Hickey, one of the leaders of the team of WHOI pilots and engineers who service *Alvin*'s ballast, battery, and motor systems.

The overhaul, required by the U.S. Navy every three to five years, lets engineers inspect every component of the sub for damage from bumps on undersea volcanoes or exposure to the super-heated fluids spewing from hydrothermal vents.

In the 41 years since *Alvin* was built, each bolt, filter, pump, valve, circuit, tube, light, and battery has been replaced at least once. At sea, maintenance is ongoing; after every dive *Alvin* pilots scrub off corrosive salt and check nooks for wayward jellyfish to ensure that dozens of electronic and mechanical parts function properly.

When *Alvin* returns to sea in spring 2006, it will travel onboard the research vessel *Atlantis* to complete recertification dives off Bermuda before returning to service for the science community.

—*Amy E. Nevala*

▲ *Alvin* is offloaded in November in Woods Hole for periodic maintenance.

Big whale, big sharks, big stink

R/V *Tioga* sent into action to perform whale necropsy at sea

Courtesy of Michael Moore, WHOI

Tim Voorheis, Gulf of Maine Productions

Courtesy of Michael Moore, WHOI

Sarah Herzig, Cape Cod Stranding Network

Sarah Herzig, Cape Cod Stranding Network

A tanker first spotted the whale on Sept. 9 about 24 miles southeast of Nantucket, Mass. It floated belly up—species unknown, cause of death a mystery.

Michael Moore, a biologist at Woods Hole Oceanographic Institution, scrambled into action. He gathered several sharp flensing knives, like those once used by whalers, to perform a messy but necessary partial necropsy to learn more about the whale. Then he and a team from the Cape Cod Stranding Network and the National Oceanic and Atmospheric Administration set out on Sept. 11 aboard WHOI's rapid-response coastal research vessel *Tioga*.

After two hours of searching for the carcass, help came from above: A pilot radioed the whale's location to *Tioga*.

"The pilot said, 'Look, I want you to know that there are at least 200 sharks down there,' " Moore said. "He told me there were more sharks than he'd ever seen in one place in 25 years of working at sea."

Moore has conducted more than 35 whale necropsies, usually on whales washed ashore. In necropsies at sea, he typically works alongside the whale in a small rubber boat deployed from larger vessels.

But not on this day, with sharks in the water. Ken Houtler, *Tioga's* captain, maneuvered the vessel alongside the whale. Moore and others tied a line around the whale's flipper and tail and cinched it to the boat's side. Floating parallel to *Tioga*, the whale stretched as long as the 18-meter (60-foot) vessel (see back cover).

Like a human autopsy, the necropsy would provide clues to why the whale, a young female finback, died. It may have been struck by a ship or become entangled in fishing gear. Moore also searched for evidence that toxic algae from a record bloom in New England coastal waters this spring may have played a role.

Gas buildup from decomposition had caused the animal to bob

▲ Left to right: Sharks surrounded a dead finback whale as WHOI's research vessel *Tioga* approached to perform a partial necropsy in September. WHOI biologist Michael Moore made a 30-foot-long incision in the whale. After the necropsy, *Tioga*'s captain, Ken Houtler, hosed down Moore. At top, *Tioga* crew member Ian Hanley creatively used earplugs to combat the decomposing whale's smell.

like an overinflated raft. To relieve the gas pressure, Moore made a series of deep, foot-long cuts—called deflationary stabs—using a knife attached to a long wooden pole. This slowly released the gas, causing the whale to flatten yet remain buoyant.

Leaning over the side of the vessel, Moore worked from bow to stern, making a 30-foot-long incision in the whale. It now resembled a dugout canoe, and Moore donned a wetsuit and rubber booties, secured a harness and safety line attached to the boat, and climbed into the whale's long incision.

Several sharks lingered nearby, feeding on the whale under the surface. Some appeared with streaks of red paint on their noses and backs after brushing against *Tioga*'s cherry-colored hull.

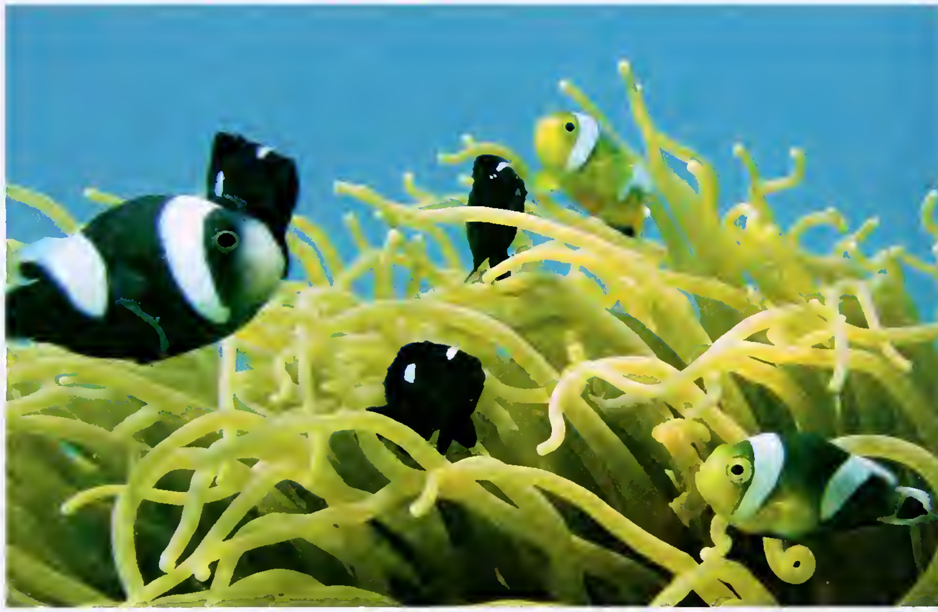
For the next hour, Moore took skin and blubber samples for subsequent analysis. As soon as he finished the necropsy, *Tioga* fled quickly. The research team's concern about the sharks had been overwhelmed by the stench of decaying whale, an odor Houtler called "straight out of a horror movie."

"Maybe some people will have nightmares about the sharks we saw," he said. "Any bad dreams I have will come from that smell."

—*Amy E. Nevala*

This project was supported by NOAA's National Marine Fisheries Service, with assistance from the Cape Cod Stranding Network.

Finding Nemo ... and other imperiled coral reef fish



Serge Planes, Université de Perpignan

▲ Scientists used a new technique to "tag" the larvae of panda clownfish off Papua New Guinea to determine how far they wandered from their birthplaces before settling down. Clownfish live on coral reefs in harmony with sea anemones, finding protection among the anemones' usually poisonous tentacles.

Scientists have long been able to tag animals on land and follow their movements and habits. But tagging and tracking fish through vast oceans is a Herculean task. Tagging fish larvae smaller than a millimeter has been impossible.

Now an international research team has demonstrated a new technique—using the common antibiotic tetracycline and DNA fingerprinting—to track fish and determine how fish populations migrate and connect to one another. Such information is essential for identifying which critical marine habitats should be set aside to protect the estimated 70 to 80 percent of fish populations whose stocks have been overfished or whose habitats have been disrupted by humans.

Woods Hole Oceanographic Institution biologist Simon Thorrold and colleagues—Geoffrey Jones of James Cook University in Australia and Serge Planes of the Université de Perpignan in France—are working in Kimbe Bay, Papua New Guinea, where anemone-filled coral reefs provide homes for clownfish—like the hero of the movie "Finding Nemo." Like Nemo, many clownfish are harvested to stock aquariums, and their numbers are being depleted on reefs throughout the Pacific and Indian Oceans.

Tetracycline is known to darken human babies' teeth when taken by mothers at certain stages of pregnancy, and similarly, it darkens the otoliths, or ear bones, of fish. By exposing developing embryos to tetracycline in specially designed incubation chambers, the team was able to indelibly mark the otoliths of tiny clownfish before they hatched and dispersed.

Reporting in the July 26 issue of *Current Biology*, the team used these telltale tetracycline-stained otoliths to track clownfish larvae. They found the larvae had settled in new anemones within 100 meters (330 feet) of their birthplaces.

The researchers also used DNA-fingerprinting techniques to determine if new settlers to a community were spawned by adults within it. They found that about two-thirds of the community's clownfish were not born nearby—but perhaps immigrated from other clownfish habitats more than 10 kilometers (6 miles) away.

The new tracking methods may be adapted for other endangered species.

—*Lonny Lippsett*

This research was funded by the National Science Foundation, the WHOI Ocean Life Institute, and the Australian Research Council.

Richard Thompson, University of Maryland

Knorr passes a milestone: 1 million miles and counting

◄ The "odometer" of WHOI's globe-trotting research vessel *Knorr* (spotted near Panama City in July, left) passed 1 million miles off Chile in October.

Two round trips to the moon. Forty trips around the Earth. That's how far the research vessel *Knorr* has cruised in 36 years at sea.

The 279-foot vessel, which was launched in 1970 and travels about 11 nautical miles per hour, passed the million-mile mark on Oct. 6, in the Golfo de Ancud, along the coast of Chile.

Captain A.D. Colburn said *Knorr* passed the milestone while traveling to Puerto Montt, Chile, after a 46-day science expedition in the Southern Ocean off Antarctica. The crew marked the occasion by ringing the ship's bell and blowing its whistle. That night on shore, they toasted the event with champagne.

Knorr, capable of traveling around the world for ocean research, is perhaps best known for carrying researchers to discover the *Titanic* wreck in 1985.

Earth can't absorb greenhouse gases indefinitely

Earth's land and oceans have been soaking up the excess carbon dioxide that humans have pumped into the atmosphere through smokestacks and tailpipes. But there are limits.

A newly developed computer model indicates that the capacity of land and ocean to absorb and store the heat-trapping greenhouse gas will reach its peak by the end of the century. Without that sponge, carbon dioxide could accumulate faster in the atmosphere and accelerate global warming.

"Time is of the essence in dealing with greenhouse gas emissions," said Scott Doney, a WHOI geochemist and member of a team that created the new computer model to analyze the workings of Earth's climate system. "We can start to address the issue now, or we can wait 50 years; but in 50 years we will have missed our best opportunity for remediation."

Digital Vision

▲ Carbon dioxide: the cup runneth over

The team reported its findings in the Aug. 9 issue of the *Proceedings of the National Academy of Sciences.*

Five years ago, Doney and colleagues—Inez Fung and Jasmin John of the University of California, Berkeley, and Keith Lindsay of the National Center for Atmospheric Research—set out to create a new climate model that included important missing pieces of the puzzle: the roles that living things, ecosystems, and ocean circulation play in cycling carbon around the planet.

The researchers factored in a wide range of complex interactions that affect how carbon circulates and where it ends up. These included: how plants on land and sea absorb and release carbon dioxide; how microbes decompose carbon in soil; how differences in forest litter can affect plant respiration—and the effects of temperature, rainfall, soil moisture, cloud cover, ocean salinity, and wind speeds on all these biogeochemical interactions.

The new model casts doubt on the oft-repeated argument that plants and ecosystems will exploit and accommodate excess carbon dioxide indefinitely. That ability ultimately is limited by other factors, such as the availability of water and nutrients, the researchers say. Meanwhile, humans show little inclination to limit their carbon dioxide emissions.

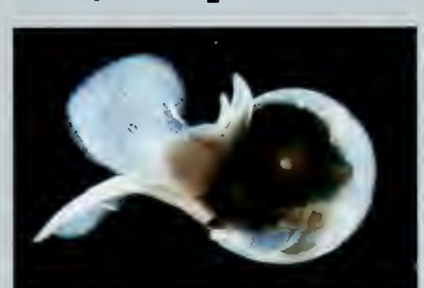
—*Lonny Lippsett*

This research was funded by the National Science Foundation, the National Aeronautics and Space Administration, Lawrence Berkeley National Laboratory, and the WHOI Ocean and Climate Change Institute.

Beyond warming the planet, buildup of CO_2 threatens the shells of ocean organisms

The buildup of carbon dioxide in the atmosphere not only warms the planet, it also leads to ocean acidification. That threatens to corrode the shells of corals and of tiny marine organisms that provide essential food for fish, whales, and other ocean life.

"We've increased the carbon dioxide in the atmosphere, and that's driving it into the ocean and changing the ocean's chemistry," said Scott Doney, a marine geochemist and a fellow of the WHOI Ocean and Climate Change Institute. Chemically, the carbon dioxide (CO_2) reacts with water (H_2O) to form carbonic acid (H_2CO_3).



Larry Madin, WHOI

▲ Small marine snails called pteropods, a diet staple in the marine food web, may have trouble forming shells if increasing carbon dioxide emissions change the ocean's pH.

"A large number of marine plants and animals, including corals, sea urchins, phytoplankton, and tiny snails called pteropods, use calcium carbonate to build shells," he said. "When the ocean gets more acidic, they have a harder time building those shells."

Doney was part of an international team of 27 marine chemists and biologists that analyzed recently compiled global ocean carbon data and computer models to study potential carbon-dioxide-related changes in the ocean. In a report published in the Sept. 29 issue of the journal *Nature*, the team predicted that the oceans—especially in fertile high-latitude regions—will become more acidic "within decades." That is much sooner than expected and probably too fast for marine organisms to adapt to the new ocean chemistry.

Pteropods are a diet staple of animals ranging from zooplankton to salmon and baleen whales. A decline or relocation of the pteropod population could spark a calamitous chain reaction throughout marine ecosystems.

Seawater is slightly basic, but the ocean surface, where sunlight fuels blooms of phytoplankton at the base of the marine food chain, is already 0.1 pH units lower than it was before the Industrial Revolution. The new report warns that the ocean will become another 0.3 to 0.4 units lower by the end of the century, which translates to a 100 to 150 percent increase in acidity.

— *Lonny Lippsett*

The research was funded by the National Aeronautics and Space Administration.

Erik Anderson, Harvard

A new twist on how squid swim

Erik Anderson was vexed by scientific papers he read in his first year of graduate studies in the MIT/WHOI Joint Program. Two groups of engineers asserted that squid propelled themselves by creating vortex rings—that is, by forcing fluid out of their pipe-shaped funnels so that the jets roll up into structures resembling smoke rings.

Anderson, who had studied squid while working on a master's degree, begged to differ. Together with his Ph.D. thesis advisor, Mark Grosenbaugh of the WHOI Department of Applied Ocean Physics and Engineering, Anderson set up a series of experiments to check the theories against some observational evidence.

Laboratory experiments, using cylindrical pipes in still water, showed that vortex rings provide efficient propulsion, so engineers presumed squid took advantage of them. "They suggested this without looking closely at a squid swimming," Anderson said. "This failure to consider the real biological system led them to wrong conclusions. We knew something else was going on."

Anderson and Grosenbaugh put live squid (*Loligo pealei*) into a flume they built in WHOI's Rinehart Coastal Research Laboratory. They added microscopic, silver-coated beads to the water, shined laser light on the squid and beads, and imaged the motion of their experimental ocean. The technique allowed them to visualize and measure the jet emitted from the squid and the water streaming by.

Analyzing the flow, Anderson saw that squid propel themselves with prolonged column-shaped jets, like the full-blast flow from a garden hose. "The squid expel fluid for relatively long periods of time," he noted, "and they don't 'puff' in the way that would be necessary to produce vortex rings."

"Rings emitted from a stationary structure—such as a smokestack or a squid starting from rest in still water—are a very efficient means for moving fluid," said Anderson, now a postdoctoral fellow at Harvard University and a WHOI visiting scientist. But when a squid is jetting through moving water, the flow from the squid's funnel (which sits above the eyes and beneath the mantle sheath) meets the current flowing over the animal. This current prevents the jet from rolling up into a ring.

The work by Anderson and Grosenbaugh was featured earlier this year in the *Journal of Experimental Biology*. It served as a reminder of the importance of real-life experiments in the fast-growing field of biomechanics.

For instance, engineers who are thinking about vehicles propelled by vortex rings "need to pay attention to the flow past the vehicle and how it interacts with their jet," Anderson said. "We need to know more about biomechanics from actually looking at real organisms before we start pouring money into so-called biologically inspired design."

—*Mike Carlowicz*

The Office of Naval Research and National Science Foundation supported this research.

A new face in town, alongside an old friend

Tom Kleindinst, WHOI

The research vessel *Atlantis* (left) is a bit like a Hollywood celebrity—well-known and often talked about, yet rarely seen around town.

In fact, when the 274-foot vessel arrived in Woods Hole on Oct. 13, it marked just the third time since its launch in 1996 that it has sailed into its home port.

Since *Atlantis* last visited in July 2003, the vessel has logged more than 50,000 nautical miles on science expeditions, primarily in the Pacific. The vessel made one short research expedition in the North Atlantic this fall, before settling in for several months of maintenance. The ship is expected to return to work in January 2006.

R/V *Oceanus* (right) celebrated its 30^{th} anniversary this fall. On Oct. 28, as the vessel returned from work in the Gulf of Maine, WHOI staff greeted the ship at the dock to celebrate three decades of hard work in the North Atlantic.

On Oct. 28, 1975, *Oceanus* departed the shipyard at Peterson Builders Inc., in Sturgeon Bay, Wisc., to cruise through the Great Lakes, the St. Lawrence Seaway, and the Gulf of Maine. It arrived Nov. 21, 1975, at its new home in Woods Hole. After five months of painting and outfitting, *Oceanus* was officially launched on its first scientific expedition in April 1976, led by Associate Scientist Robert Beardsley, now a scientist emeritus.

Scientists discover 'seasonal pumping' of water between ocean and aquifers

Knee-deep in water, WHOI hydrologist Ann Mulligan was working in Waquoit Bay on Cape Cod, investigating fresh groundwater flowing into the coastal ocean. Across the beach, she spied Holly Michael and Charles Harvey of the Massachusetts Institute of Technology, who were examining salty and brackish water flowing underground. Thus began a collaboration that has cleared up a mystery of why so much salty water emerges from aquifers into the coastal ocean.

The researchers discovered a counterintuitive seasonal pumping system at work: Groundwater flows out to sea mostly in midsummer, when conditions in Massachusetts are driest and underground water supplies would seem to be at their lowest level. In winter, great volumes of salt water are drawn landward from the ocean to fill aquifers, which you would think would be filled by rain and snow percolating downward.

The findings were published in the Aug. 25 issue of the journal *Nature*.

Scientists have known for some time that groundwater discharging into the ocean from aquifers can be salty, fresh, or a brackish mixture of the two. But how does salt water get into the fresh aquifers? Scientists know that seawater seeps inland—via tidal action, waves lapping on the beach, and other forces. But none of those processes moves enough ocean water inland to account for all of the salty water flowing outward.

Michael, Mulligan, and Harvey measured the flow of water in the subterranean mixing bowl of Waquoit Bay, near WHOI. They used seepage meters to measure the rate of groundwater flow into the bay during summer, and piezometers (which measure pressure) to determine the flow during winter when the sea surface was frozen. The measurements indicated that groundwater flows into the bay during summer, and bay water flows into the aquifer during winter.

The team used mathematical models to show that it can take several months before winter rain and snow seeps down through the layers of soil, sand, and rock. As a result, seawater is drawn in to fill aquifers during winter until fresh water arrives. As fresh water reaches the aquifers in spring and summer, the water table slowly rises and reaches a threshold where momentum tips and forces water—now a fresh and salty mixture—to flow back toward the sea.

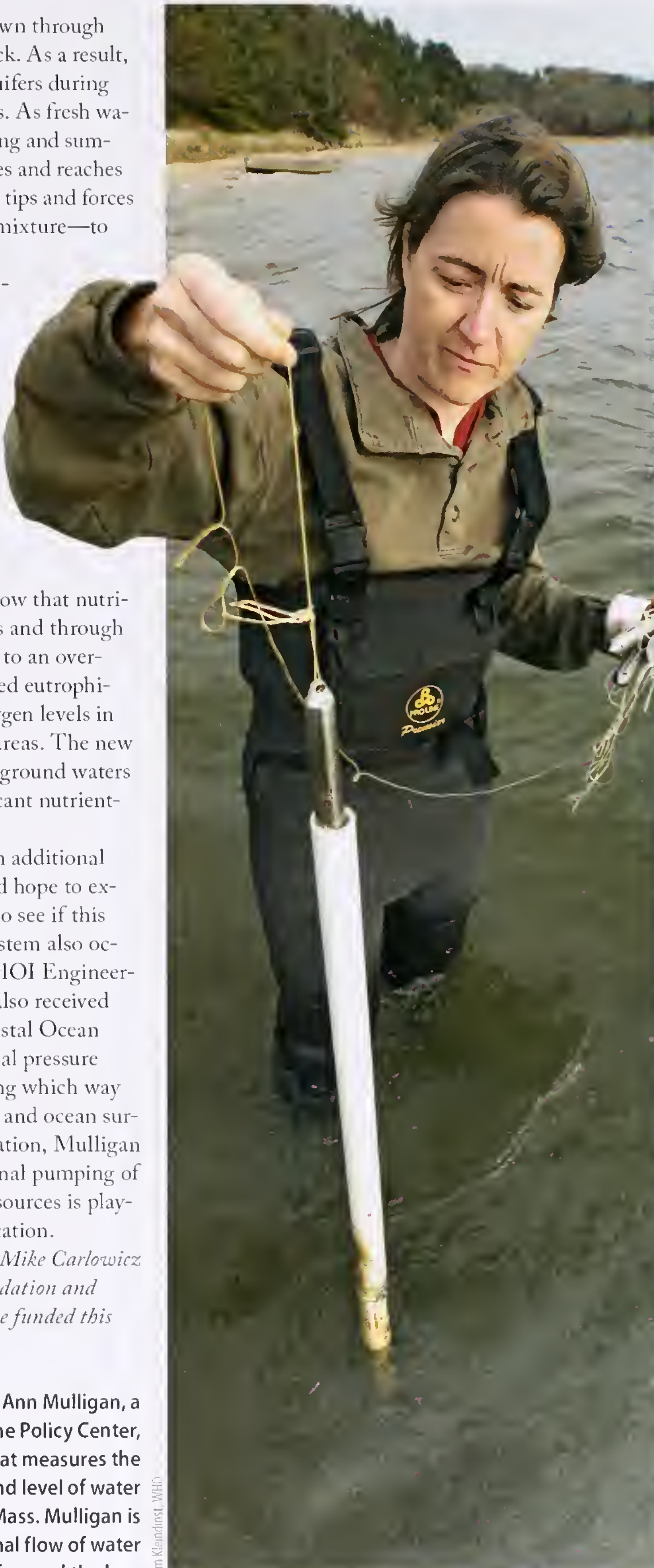
Mulligan notes that the inflowing seawater can acquire a lot of dissolved nutrients, contaminants, and trace elements from the ground. When it flows back out in summer, it may carry large amounts of nutrients into coastal waters—at just the time of year to feed blooms of marine plants.

Environmental experts know that nutrients running off land surfaces and through fresh groundwater contribute to an overgrowth of marine plants, called eutrophication, which can deplete oxygen levels in seawater and deaden coastal areas. The new research points to salty underground waters as another potentially significant nutrient-loading source.

Mulligan and Harvey plan additional fieldwork in Waquoit Bay and hope to extend their studies to Florida to see if this natural, seasonal pumping system also occurs there. Mulligan and WHOI Engineering Assistant Alan Gardner also received a grant from the WHOI Coastal Ocean Institute to create a differential pressure logger, a new tool for detecting which way water flows between aquifers and ocean surface water. With that information, Mulligan can test the theory that seasonal pumping of nutrients from underground sources is playing a role in coastal eutrophication.

—*Mike Carlowicz*

The National Science Foundation and WHOI Coastal Ocean Institute funded this research.



► Assistant Scientist Ann Mulligan, a hydrologist in the WHOI Marine Policy Center, examines a data logger that measures the conductivity, temperature, and level of water in a well in Waquoit Bay, Mass. Mulligan is investigating the seasonal flow of water between aquifers and the bay.

Tom Kleindinst, WHOI

Should Oysters Be Put on Endangered Species List?

Eastern oysters in Chesapeake Bay were not happy as clams, and neither was Wolf-Dieter Busch.

The environmental consultant from Maryland knew that overharvesting, habitat loss, poor water quality, and diseases had devastated a once-abundant wild oyster population. He was "distressed by the slow and disorganized efforts to restore the Chesapeake Bay's ecosystem," he said.

"Then the Maryland and Virginia governments indicated that oysters in the Chesapeake Bay were now commercially extinct," Busch said, and they proposed what he called a "quick fix"—introducing disease-resistant, harvestable Asian oysters. Busch feared that the exotic species would compete with any remaining eastern oysters for food and space, and maybe even cross-fertilize with them—spelling doom for the wild native species.

In January 2005, Busch filed a petition to the National Marine Fisheries Service (NMFS) to place the eastern oyster (*Crassostrea virginica*) on the federally protected threatened and endangered species list. To the surprise of many, the uncommon, one-person petition cleared one regulatory hurdle in May. To the surprise of Busch, the petition stirred storms of protest from both environmentalists and critics of the Endangered Species Act (ESA).

"The petition was Chesapeake-centric," said William Walton, shellfish and aquaculture researcher with the Woods Hole Sea Grant and Cape Cod Cooperative Extension programs. Placing the oyster on the endangered species list, he said, could outlaw commercial and recreational eastern oyster gathering nationwide, even where they are abundant. It would also prohibit oyster aquaculture and possibly inhibit wild oyster restoration efforts by restricting the search for disease-resistant wild oyster strains to reseed previous oyster habitats.

The controversy partly stemmed from the way the Endangered Species Act is written. Under the act, invertebrates—unlike vertebrates—can't be considered endangered in a portion of their range; they must be listed everywhere or nowhere. Also, a petitioner cannot ask that a species be listed as "threatened," rather than "endangered"; NMFS must make that distinction. A "threatened" designation—which Busch says he sought—would allow flexibility in managing the oyster population, allowing exemptions for aquaculture and easing restrictions in particular regions.

Shellfish farmers from New England to the Gulf of Mexico testified vehemently against the petition before the U.S. House Committee on Resources in July. At the same time, the committee chair, Richard W. Pombo, R-Calif., author of a recently passed House bill that rolls back habitat-protection provisions in the ESA, called the petition "a big hammer" and used it as evidence of problems with the act. Environmental groups, according to Busch, said the oyster petition controversy was adding ammunition to attacks on the ESA.

"Any individual has the right to (file a petition), but it's not an everyday occurrence," said Teri Frady, an NMFS spokesperson in Woods Hole, Mass. "The agency responds to all petitions," though many never get past the initial 90-day review. Busch's petition did, and NMFS assembled a team of state and federal fisheries experts to conduct a "full status review" of the species, using "the best available scientific and commercial information" on historic and current populations, conditions, protection efforts, habitat destruction, harvesting levels, disease, predation, and possible subspecies.

The team's report was due before January 2006. But in October, Busch withdrew his petition. Busch said he was "blindsided" by the barrage of negative reactions to his petition by people who did not fully understand the act or the petition process and concluded that his petition would lead to "endangered" status and the most severe restrictions for the eastern oyster.

Marta Nammack, national ESA listing coordinator at NMFS, said she could not remember any previous incidence of an ESA petition being withdrawn. Nevertheless, NMFS has decided that the already established review team will proceed with its study of the eastern oyster, including in Chesapeake Bay.

Which is precisely what Busch wanted in the first place.

— *Kate Madin and Lonny Lippsestt*

Diane Murphy, Cape Cod Cooperative Extension

▲ **Oysters produce about half of Cape Cod's commercial shellfish aquaculture income, said William Walton of the Cape Cod Cooperative Extension program, working to restore native oysters in Wellfleet, Mass.**

Action, camera ... lights

Deep-sea light post illuminates ocean's perpetual night

Exploring the seafloor can be like using a flashlight to find something in a dark basement. Just one-third of a mile beneath the sea surface, ambient light fades to black, requiring oceanographers to beam their own light to see what's around them and to take photos and video of the deep.

Until now, illumination has come mainly from multiple lights mounted on deep-sea vehicles. In the summer of 2005, Woods Hole Oceanographic Institution scientists and engineers designed something entirely different: a tall, portable light system. Named the "deep-sea light post," it blazes with a single, 1,200-watt bulb on top of an 8-foot pole, powered by five 100-pound batteries in watertight housings.

The light post's illuminating power is 20 times stronger than that of the average 60-watt household bulb. The device gives off nearly as much light as each bulb used to illuminate Boston's Fenway Park.

Best of all, the 1,400-pound instrument—which weighs 200 pounds in water—can be moved around the seafloor by the remotely operated vehicle *Jason 2*. This provides oceanographers with views of large seafloor features from different angles, essentially transforming areas of the deep sea into a photography studio.

As high-resolution photography and video have become more affordable and routine in deep-sea research in the last decade, so has the need for powerful and adaptable lighting systems. WHOI geologist Dan Fornari spearheaded the project this summer to build the light post in just six weeks with several WHOI researchers and engineers, including Marshall Swartz and Steve Liberatore.

It was first tested in September 2005 for use with a new University of Washington high-definition video camera mounted on *Jason 2* that provided live broadcasts from the seafloor to the Internet. WHOI engineer Robert Fuhrmann helped operate *Jason 2*.

"SPECTACULAR," University of Washington oceanographer Debbie Kelley wrote of the light post in an e-mail after testing the instrument on the Juan de Fuca Ridge offshore Seattle. There, the rugged and strangely beautiful seafloor landscape is carpeted with crabs, snails, and tubeworms living around tall hydrothermal vent chimneys, some the size of six-story buildings.

"The camera worked, the light turned on, and it was as if we had walked into the land of the Hobbit," Kelley wrote from the research vessel *Thomas G. Thompson*. "It gave us views of the field we have never seen before. It was something I will not forget for a long time."

The light post's broad, bright beam gave Kelley and John Delaney, both lead scientists on the expedition, a chance to see a large portion of a 25-meter (82-foot) hydrothermal chimney called Hulk.

"For the first time, I got a big overview of the structure," Kelley said. "Normally I'm just getting little glimpses."

Powerful lights, adapted for use in the cold temperatures and crushing pressure of the deep ocean, have been developed by the San Diego-based company DeepSea Power & Light and used on diving vehicles at WHOI since the early 1990s. Hollywood directors have even capitalized on this type of intense lighting, perhaps most famously in filming underwater scenes in the 1997 movie *Titanic*.

—*Amy E. Nevala*

Funding to develop the deep-sea light post came from the National Science Foundation.

Scientific (and surfing) safari

At work and play, a graduate student displays his passion for the ocean

Eric Montie has a deep tan, photos of huge waves taped above his computer, and a penchant for grabbing his short board and racing to the beach at a moment's notice. He is—undeniably—a surfer dude.

But watch him spend hours at a magnetic resonance imaging machine to photograph a dolphin's skull then carefully extract its brain to detect the presence of chemical contaminants. It's evident that his interest in the ocean runs much deeper than finding the gnarliest wave.

As a graduate student in the MIT/WHOI Joint Program, Montie is working to develop methods to better understand if toxic chemicals found in the marine environment can affect brain development in dolphins. Among the chemicals Montie is exploring are flame retardants known as polybrominated diphenyl ethers, or PBDEs, which were widely used in furniture, foam, plastics, and computers before some mixtures were banned in 2004.

PBDEs are chemical cousins of polychlorinated biphenyls (PCBs), industrial chemicals that were banned in the 1970s because they harm animal life. The chemicals take decades to break down in nature, and they move up the food chain by accumulating in body fat.

Detecting and measuring these chemicals in the oceans is difficult, but scientists do know that once the chemicals get into the environment, they disperse widely. They show up in the Atlantic white-sided and common dolphins that Montie studies, as well as in California tern eggs and Arctic polar bears.

In lab experiments with rodents, scientists have learned that the chemicals can interfere with neurological function and the thyroid hormone system, with potential harm ranging from cognitive defects to hearing loss.

"Picture a deaf, dumb dolphin trying to find food," Montie said.

Montie learned to surf in Rhode Island, not far from his Connecticut home. As his bottom-turns, cutbacks, and floaters improved, so did his knowledge of and interest in ocean currents, winds, and the activities of marine mammals. When Eric was young, his father, Bill Montie, recalls walking on the beach and fielding "a million questions from Eric" about the dead crabs and fish they found.

"He wanted to know, 'Were they poisoned? Didn't they eat the right food?' " Bill Montie said.

For his research at WHOI, Eric Montie is asking similar questions about marine mammals. Unlike laboratory mice, however, dolphin specimens aren't as easy to get, and, more important, they are a protected species, so no research can be conducted on them without permits. Over the years, Montie—with assistance from the Cape Cod Stranding Network—has obtained samples from dolphins that died or were euthanized after stranding on beaches in Massachusetts.

In the past, scientists had examined the mammal's brain as a whole to determine what contaminants had accumulated in it, said Chris Reddy, a chemist at WHOI who hosted Montie in his lab this summer. Montie is taking that research a step further by studying whether contaminants accumulate in and affect specific brain regions—those that depend on thyroid hormones for maturation, such as the cerebellum, corpus callosum, and hippocampus.

So far, in three dolphins, Montie has performed chemical analyses on gray matter in the cerebellum, the part of the brain responsible for balance and movement. Preliminary results have shown higher-than-expected levels of PBDEs.

"Now that we know PBDEs can accumulate in dolphins' brains, we would like to understand what this means for their health," he said. "There's a potential that these chemicals could have negative effects. Right now, we just don't have enough baseline information on dolphin brains, so perhaps our research will shed some light."

Surfing, Montie said, has provided balance during intense months in the lab, and his lab mates often check in with him when looking for the latest information on coastal weather. "He's the guy who has the handle on what's happening with currents, where the winds are blowing," said Regina Campbell-Malone, a graduate student in biology.

His advisor Mark Hahn, a senior scientist and toxicologist at WHOI, doesn't blink when Montie occasionally disappears from the lab at, say, noon on a Tuesday. He knows that waves can be a siren

call to the New England surfer in autumn, when beaches in Massachusetts and Rhode Island empty of tourists, Atlantic waters still hover just below 70 degrees, and southern hurricanes kick up northern swells.

"I don't mind when he dashes out," Hahn said, "because the rest of the time he's in here working his tail off."

Montie had planned to apply to medical school following his undergraduate degree in zoology in 1993 at the University of Rhode Island. That changed after he borrowed his father's white van and drove 12,000 miles through two dozen national parks. For three months, he and two friends, subsisting on cornflakes and spaghetti, hiked and camped in parks from Missouri to Washington.

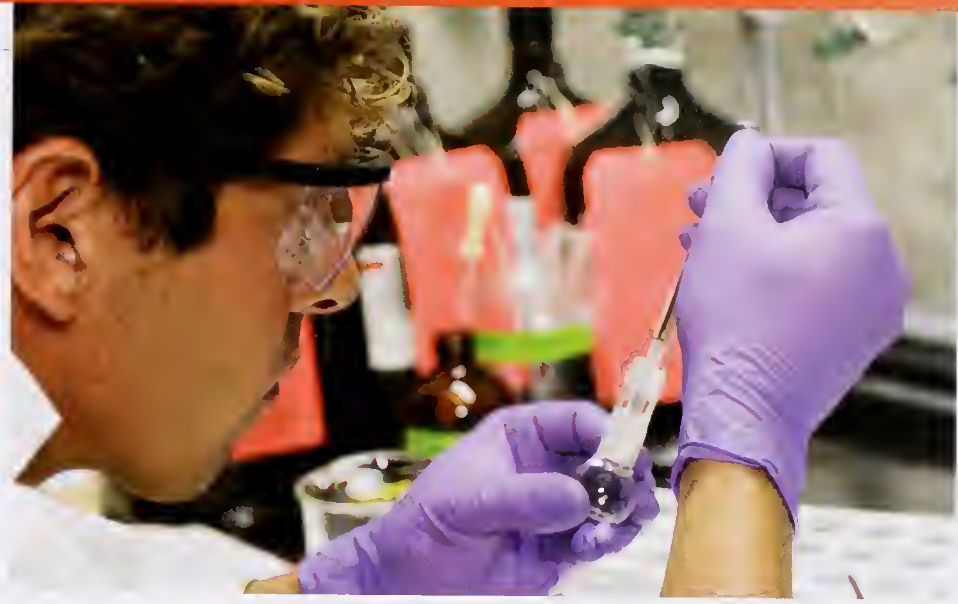
Mesmerized by the sweep of mountains, rivers, and grasslands so unlike the small states and crowded cities of the East Coast, Montie fell hard for the West's unspoiled beauty. After returning that fall, he shelved his medical school applications. "That big dose of open space and wild land made me realize I wanted to understand the natural environment," he said.

Six months after the trip west, Montie landed an internship at an Environmental Protection Agency research lab in Rhode Island studying how toxic metals affect two species of shrimp. The volunteer position helped him focus his scientific interest in environmental toxicology, and in 1995 spurred him to graduate school at Clemson University, where he dissected and analyzed the brains of deer mice to learn how the insecticide dieldrin alters their ability to adapt to the cold.

Ultimately, though, the ocean drew him back. "I just couldn't get away from surfing," he said.

—*Amy E. Nevala*

Eric Montie's research is supported by the WHOI Ocean Life Institute, the WHOI Academic Programs Office, the Environmental Protection Agency STAR Fellowship Program, the Office of Naval Research, the National Woman's Farm and Garden Association, Quebec Labrador Foundation/Atlantic Center for the Environment, the National Oceanic and Atmospheric Administration, and Shields MRI of Cape Cod.



▲ Eric Montie says surfing provides balance during intense months in the lab, where he examines how chemical contaminants in the ocean can affect dolphins' brains and hormones.

▲ Montie prepares to take a magnetic resonance imaging scan of the brain of a stranded and euthanized dolphin.

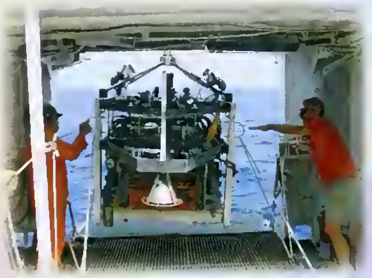
▲ Montie removes a stranded dolphin's thyroid gland with fellow graduate student Joy Lapseritis and former student Thomas Abbott.

Photography by Tom Kleindinst WHOI

Bubbling crude

SANTA BARBARA, CALIF.—There is an oil spill every day off the California coast, but the culprits aren't people. Nature pumps 4,200 gallons of petroleum per day into the ocean through "seeps"—cracks in the seafloor where fossil fuels leak from underground reservoirs. To Chris Reddy and Bob Nelson of the WHOI Department of Marine Chemistry and Geochemistry, the oil seeping naturally off Santa Barbara looks a lot like processed oil spilled by tankers in New England waters. Working with Dave Valentine of the University of California, Santa Barbara, Nelson (background) and WHOI Research Specialist Larry Ball sampled the petroleum to understand how microbes and other processes naturally weather and deplete oil in the marine environment.

Chris Reddy, WHOI



Char-Shine Liu, National Taiwan University

10,000 photos under the sea

EAST CHINA SEA—Three WHOI scientists snapped 10,000 photographs of a 16-by-24-kilometer (10-by-15-mile) swath of seafloor suspected to host gas hydrate deposits, a potential fuel source. Working with Taiwanese researchers, Dan Fornari (above right), Marshall Swartz, and Adam Soule of WHOI spent four days in September and October on *Ocean Researcher-1*, a National Taiwan University vessel. They used TowCam, WHOI's deep-sea digital towed camera, to locate and photograph the gas, which seeps from seafloor vents and fissures. Taiwanese researchers will use the photos to plan for further study, including detailed seafloor surveys.

An oasis in the ocean

Cedar McKay, University of Washington

COSTA RICA DOME—For six months a year, the Costa Rica Dome—a swath of ocean 200 to 400 kilometers (125 to 250 miles) off western Central America—blooms with a bounteous crop of microscopic plants and bacteria. Seasonal winds not only bring up nutrients from the deep, but also metals that are usually scarce in the ocean: zinc, iron, copper, cobalt, and cadmium. These trace metals are key components of enzymes that drive metabolic reactions in marine life. WHOI marine chemists Mak Saito, Jim Moffett, and Dan Repeta and biologist Eric Webb explored many aspects of this phenomenon this summer aboard R/V *Knorr* with colleagues, including (foreground to background) Bethany Jenkins (Univeristy of Rhode Island), Amy Simoneau (WHOI), Sacha Wichers (WHOI), and Kate Achilles (University of California, Santa Cruz).

Spring in Antarctica: No daffodils, but lots of microbes

ROSS SEA—Biologist Rebecca Gast and colleagues spent autumn 2005 aboard the icebreaker *Nathaniel B. Palmer* off Antarctica, where spring weather in the Southern Hemisphere was melting the pack ice. Gast's group identified changes in the microbial community as the season progressed. One goal was to determine whether microbes that were frozen into the ice last fall would "seed" the annual spring blooms, or whether the spring-blooming microbes are actually present in seawater all year long. Gast also continued her investigations of an unnamed microbe that eats algae and removes their photosynthetic plastids (an organelle within the cytoplasm). The algae incorporate the plastids and keep them alive and photosynthesizing.

Becky Gast, WHOI

On top of a seamount, all covered with corals

PICKET SEAMOUNT—WHOI biologist Lauren Mullineaux joined colleagues from the universities of Connecticut and Maine aboard the WHOI research vessel *Atlantis* on an October expedition to Picket Seamount, one in a chain of volcanic peaks that rise abruptly from the seafloor east of New England near Georges Bank. The seamounts harbor long-lived corals (such as the still-unnamed species of *Paragorgia*, left), which thrive in the dark depths and sustain communities of invertebrates and fish. Mullineaux used the submersible *Alvin* to observe and survey coral-inhabited areas and to collect specimens of deep-growing corals. Photo courtesy of 'Deep Atlantic Stepping Stones' scientific party, NOAA, and the Institute for Exploration

'Eighteen-Degree Water'

GULF STREAM—Exposed to wintry air, warm waters just south of the Gulf Stream surrender their heat to the atmosphere, become colder and denser, and then sink. They form a distinct water mass, discovered in 1959 by WHOI oceanographer Val Worthington and called (after their characteristic Celsius temperature) "Eighteen-Degree Water," or EDW. Formed over successive winters, this water mass constitutes a long-term memory of the climate system. In November, WHOI oceanographers made the first expedition in a five-year, nine-institution project to understand the formation, storage, and evolution of EDW. The research team aboard R/V *Oceanus*, led by Dave Fratantoni and Bob Weller (in yellow jacket, with WHOI researcher John Lund) deployed five moorings, five surface drifters, and 17 floats to track EDW. The team will return to the area on R/V *Atlantis* in February.

Sean Whelan, WHOI

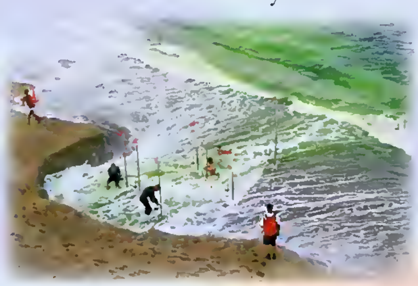
Around the world for 80 days

INDIAN OCEAN—For the third consecutive year, WHOI geophysicist Jian Lin was not home for the holidays. This year, he was invited to be U.S. chief scientist on two 40-day cruises aboard *DaYang YiHao*, a Chinese oceanographic ship that circumnavigated the globe for 300 days. Below, Lin (left) and Professor John Chen and graduate student Zhu Jian (right) of Peking University deploy a sensor to detect hydrothermal vent plumes in the equatorial Pacific Ocean this fall. The second cruise, which started in November, took Lin to the Indian Ocean to search for vents and to map the site of the seafloor earthquake that spawned the devastating 2004 tsunami.

Min-Yu Mi, China Central Television

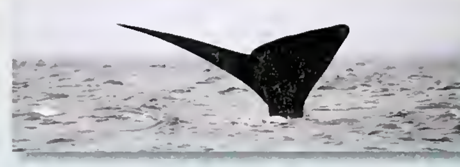
On the beach

DUCK, N.C.—For three days in September, they dug holes in the beach, but not for sand castles. WHOI scientists Steve Elgar, Britt Raubenheimer, and a team of graduate, undergraduate, and high school students excavated a hole 1.8 meters (5.9 feet) deep and 10 meters (33 feet) wide at the U.S. Army Corps of Engineers Field Research Facility. Using current meters, surveying equipment, and dyes, they measured the flow of sand and water as the hole was covered and uncovered by tides. The goal was to learn how long a crater would last in the swash zone, and whether it would create rip currents or other flows of water that could impede amphibious landing craft.



Britt Raubenheimer, WHOI





WHOI Right Whale Initiative accelerates research

The situation is urgent: Seventy years after whaling was banned, the North Atlantic right whale population has not recovered. Only 300 to 350 remain, and the species is headed toward extinction.

The threats remain dire: Right whales are frequently struck and killed by ships or become fatally entangled in fishing gear, because their migratory routes overlap with major fishing areas and heavily trafficked shipping lanes along the east coasts of the United States and Canada. In addition, the whales aren't reproducing consistently or fast enough to increase their numbers—perhaps because of disease, pollutants, poor food supplies, or genetic problems.

In November 2003, the WHOI Ocean Life Institute convened a forum in Woods

What can whales hear?

Why don't right whales hear large ships coming and avoid collisions? Can underwater alarm systems be designed to warn whales of approaching vessels? Researchers have been thwarted in their attempts to answer these questions by a lack of fundamental knowledge of how—and how much—whales can hear.

With funding from the Right Whale Initiative, WHOI biologists Darlene Ketten and Susan Parks generated CT scan images of the internal anatomy of mammal ears to provide the first estimates of the frequency range of right whale hearing. Measuring hearing in large, rare, elusive marine mammals would have been impossible without the WHOI CT scan facility for oceanographic research. It has enabled Ketten and colleagues to react quickly to scan and image the ears of whales that stranded and died, as well as ears of other large mammals for comparison.

The researchers measured cochleas—the spiral structures found in all mammal inner ears. By comparing whale cochleas with those of land mammals (whose hearing ranges are known), Ketten showed that whales have some of the widest hearing ranges of any mammal. To test whether their right whale hearing estimates hold up in real life, Parks teamed with WHOI biologist Peter Tyack and colleagues, who place noninvasive suction-cup "tags" on whales to record ambient sound and whale behavior. The combined work has allowed scientists to determine what sounds whales respond to and to consider possible ship alarm strategies to help avoid collisions.

Tom Kleindinst, WHOI

▲ To learn about marine mammal hearing, researchers use the WHOI necropsy and CT scan facility to reveal the internal anatomy of ears.

What's the breaking point of bones hit by ships?

Collisions with ships often leave right whales with broken jaws, but scientists have lacked even the most rudimentary knowledge of whalebone structure and properties to determine how bones stand up to impacts from ship hulls. Regina Campbell-Malone, a WHOI/MIT Joint Program graduate student, WHOI biologist Michael Moore, and colleagues from the University of New Hampshire conducted biomechanical studies of whale jawbones to obtain the first detailed data on the bones' flexibility, strength, and breaking points. Such studies will help establish the threshold speeds and masses of vessels that will or will not kill whales in collisions. They will help determine if reducing vessel speeds in critical right whale habitats would reduce the likelihood of fatal fractures.

To test the jaw's biomechanical response to applied stress, the researchers suspended jawbones from a crane and loaded 1,000 pounds of weights onto a pallet hanging from the bone. Small sensors called strain gauges measured the bones' strength limitations and breaking points. The researchers have also used CT scans of jawbones to investigate their density and structure, including their interior structure, to gain insights into their capacities.

Tom Kleindinst, WHOI

▲ Graduate student Regina Campbell-Malone studies the breaking point of whale jawbones, which are often fractured by collisions with ships.

David Wiley, NOAA

o help conserve an endangered species

Hole, gathering scientists from several institutions, along with representatives from government and industry, to devise a collaborative research plan to accelerate our understanding of right whale habits and habitats. The Institute began a Right Whale Research and Conservation Initiative, with the aim of supplying knowledge, tools, and strategies for more effective conservation efforts.

Catalyzed by funding from the Penzance Foundation, the North Pond Foundation, and the Virginia Wellington Cabot Foundation, the Ocean Life Institute launched several research projects that blend the expertise of scientists at WHOI and other institutions. On the following pages, we report on some of their initial efforts.

Is there a link between food supplies and pregnancies?

Like North Atlantic right whales, South Atlantic right whales (a separate but related species) were also hunted to precariously low levels. But the southern right whale population has rebounded dramatically since whaling was banned. The photos below offer a clue: The southern whales often have a major roll of fat behind their blowhole, which their northern cousins lack.

Carolyn Angell, a WHOI guest student, and her advisor, WHOI biologist Michael Moore, developed a cantilevered pole system to measure blubber thickness in right whales swimming in the ocean. Their research indicates that whales likely require adequate nutrition and body condition to achieve successful pregnancies. Miller, who defended her doctoral thesis on the results of the research in August 2005, also showed a link between the amount of food available to whales in different years and their ability to produce calves.

The research has spurred a new study by WHOI guest student Nadine Lysiak to analyze isotopes in whale baleen, the fibrous food-filtering material in their mouths. As they grow, whales incorporate into their baleen isotopes from their prey and from the waters they swim in. The experimental technique offers the potential to provide annual histories, much like tree rings, of where and when the whales traveled and what they ate. The work may also pinpoint previously unrecognized migration patterns or feeding habitats—or changes in these caused by shifts in ocean circulation or climate. A gift from WHOI Trustee Hardwick Simmons and his wife, Sloan, is funding the research.

Photos by Carolyn Angell, WHOI

▲ A southern right whale (inset) shows a roll of fat behind its blowhole, which northern right whales often lack.

What factors are preventing population growth?

Assessing the state of the North Atlantic right whale population—and ways to preserve it—requires the messy but essential task of determining how and why whales are dying. WHOI biologist Michael Moore, co-investigator William McClellan of the University of North Carolina, Wilmington, and colleagues from many other institutions have undertaken six necropsies in the past 18 months, determining that the whales were mainly killed by ship collisions and fishing gear entanglements. The animals were predominantly pregnant females, which represents serious lost potential for future births.

Statistical models of whale population dynamics by biologist Hal Caswell and other WHOI researchers have indicated that the deaths of mature female right whales constitute a critical factor for survival of the species. The study showed that if just two to three adult female deaths could be prevented each year, the population trend would switch from declining to growing. Caswell has continued his studies to identify other sensitive factors that could be targeted to help devise effective management strategies that will bolster population growth.

—Lonny Lippsett

Regina Campbell-Malone, WHOI

▲ WHOI biologist Michael Moore (top) begins a necropsy to determine what killed this right whale.

Diving into the right whale gene pool

What is compromising the endangered species' ability to reproduce?

Like forensic detectives, a multi-institutional team of scientists has followed a thread of DNA from the highly endangered right whale population across the oceans and back through generations.

Using genetic techniques, the scientists undertook two studies: The first explored whether 16th-century Basque whalers struck a devastating blow to the North Atlantic right whale population and gene pool. The second sought to determine if a lack of genetic diversity (inbreeding) is now compromising the species' ability to reproduce.

Both studies resulted in surprising findings that change the explanations for the whale's near-extinction. They also will revise strategies to conserve the species, which has not recovered in the 70 years since whaling was banned. Fewer than 350 remain, and the whales are having fewer offspring than expected.

In the first study, scientists from the New England Aquarium (NEAq) in Boston and Trent University in Ontario extracted DNA from skin samples collected from 56 percent of North Atlantic right whales identified since 1935, including 66 percent of the current population. By correlating the samples with a photographic catalog of whales identified over 26 years by NEAq, the researchers created "family trees" or genealogical charts for right whales.

"It shows us who mated with whom, who had successful calves, and who isn't having offspring anymore," said Trent University biologist Brad White.

The DNA profiles turned up genetic material in calves from fathers that have never been identified. These new paternity data suggest that there may be many more male right whales—representing perhaps an uncounted 10 to 15 percent of the entire male population—living in currently unknown habitats.

Family tree analyses also showed that successful pregnancies occur only between whales with sufficiently different genetic profiles. Inbreeding and genetic similarity in animals (including humans) often result in unsuccessful fertilization and in high rates of spontaneous abortion. The study suggests that the low level of genetic variation in the small North Atlantic right whale population may partly explain its low reproduction rate, said Moira Brown and Rosalind Rolland at NEAq.

Moira Brown, New England Aquarium

▲ Equipped with bug jacket and sterile drill bits (lower right), Trent University graduate student Brenna McLeod extracts samples for DNA analyses from two whale rib bones, perhaps left behind by 16th-century whalers, in Five Leagues Harbour on the lower north shore of Quebec.

For the second study, scientists from NEAq, Trent, and Woods Hole Oceanographic Institution traveled to remote regions of eastern Canada to search for old bones left behind by Basque whaling.

"In 1535, Basque fishermen initiated a whale fishery in the Strait of Belle Isle, between what we now call Newfoundland and Labrador," said WHOI biologist Michael Moore. "To the Basque it was a land of opportunity, a gold rush for whale oil to light Europe, which lasted to the early 1600s."

In the 1980s, scientists exhumed preserved whale bones from the wreck of a Basque galleon that sank in 1565 in Red Bay, Labrador. Based on their physical characteristics, half the bones were initially identified as right whale bones. That led scientists to believe that extensive Basque whaling caused a dramatic decrease in the North Atlantic right whale's population and extensive genetic loss.

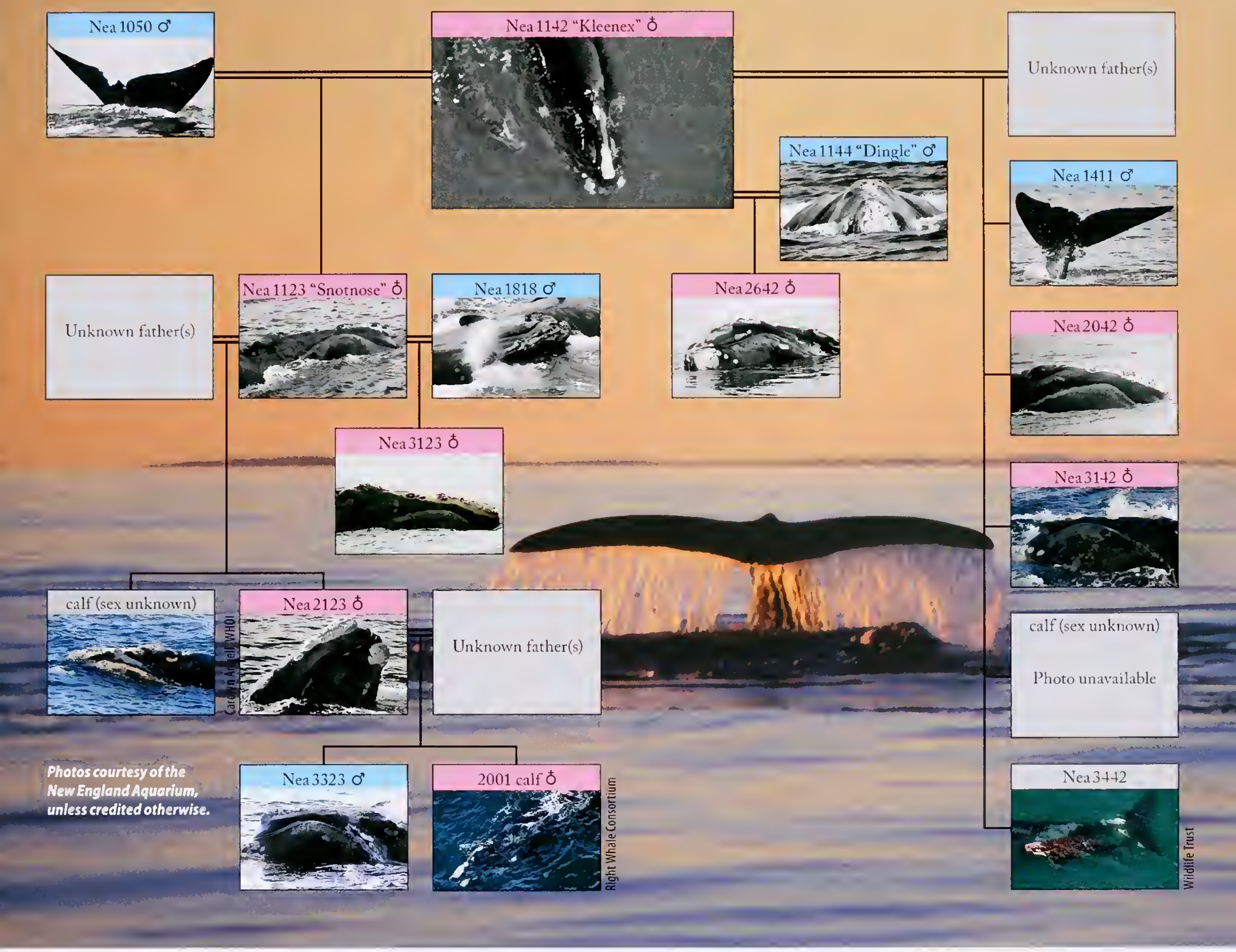
With the advent of molecular genetic techniques, scientists began to extract DNA from the old bones. A pilot study in 2003 showed that DNA could be gathered from more weathered bones found on land, significantly increasing the potential number of samples to test the Basque theory.

In 2004, the research team launched an expedition aboard Moore's sailboat *Rosita* to search for samples that had rested undisturbed on beaches for 500 years. They ventured near previously identified Basque whaling ports on the Strait of Belle Isle, which Moore called "a place of cold water, icebergs, gales, and fog, often all at once."

Many sites were identified by the presence of terra cotta tiles, which the Basques used first for ballast and then for roofing over cooperages and blubber-rendering ov-

The "Kleenex" Family Tree

Combining DNA analyses with an extensive catalog of photo-identified whales, researchers can now construct "family trees" for right whales, like this one for a matriarch whale named "Kleenex."



Photos courtesy of the New England Aquarium, unless credited otherwise.

ens. The researchers walked along the shore, sometimes through vegetation infested with mosquitoes and black flies, to collect bones. In 2005, the team investigated 16 more potential Basque whaling stations in ever more remote areas, many inaccessible by road.

DNA analyses were conducted on 81 of the 215 bones collected in 2004. The results showed that 80 came from bowheads, one from a finback, and none from right whales. To date, 210 bones from 10 known Basque whaling sites have been analyzed, and only one specimen came from a right whale. The genetic characteristics of that single right whale bone resembled those of whales in the current population.

The studies suggest that the Basques had little impact on right whales and that the species' population size and genetic variability has been low for much longer than previously believed. If that's true, the species' potential to recover is lower and may take longer than previously assumed.

"These initial analyses have rewritten the history of the species, revised estimates of historic population size, and revealed previously unknown aspects of reproductive success," the researchers said. "They could have significant implications for present recovery strategies."

—Lonny Lippsett

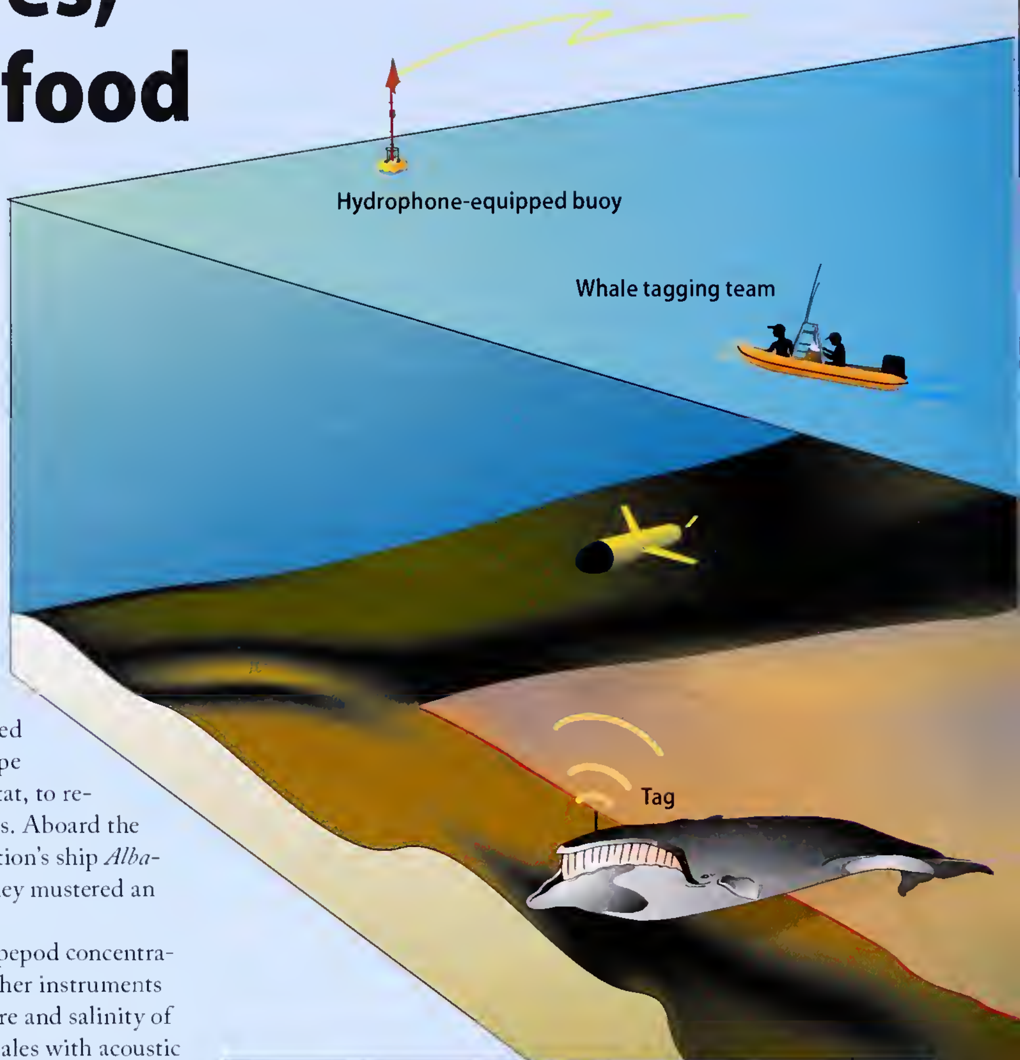
This research was funded in part by the Penzance Foundation, through the WHOI Ocean Life Institute's Right Whale Research and Conservation Initiative. The research team for the genetic diversity study, led by Moira Brown and Rosalind Rolland at NEAq, included Heather Pettis (NEAq); Brad White, Roxanne Bower, Tim Frasier, and Brenna McLeod (Trent University); marine archaeologists Robert Grenier and Willis Stevens from Parks Canada, and Stephen Cumbaa from the Canadian Museum of Nature. The research team for the Basque bone study included Brown, McLeod, White, and Michael Moore (WHOI).

To find whales, follow their food

The average adult right whale consumes about a ton of food a day, eating billions of tiny crustaceans called copepods that are packed with protein and calorie-rich oils.

"To whales, copepods are juicy, greasy Big Macs, in a really small package," said Mark Baumgartner, a biologist at Woods Hole Oceanographic Institution.

Like hungry people at a buffet, North Atlantic right whales gravitate to places where vast, dense patches of copepods periodically appear. If scientists know where and when copepods will show up, they can predict where whales will be. That offers vital information for efforts to manage ship traffic and fishing to avoid encounters that often kill these endangered whales.



In 2005, Baumgartner and colleagues launched a pilot study in the Great South Channel off Cape Cod, a well-known springtime right whale habitat, to reveal the mysteries of right whale feeding grounds. Aboard the National Oceanic and Atmospheric Administration's ship *Albatross IV* and the WHOI research vessel *Tioga*, they mustered an arsenal of scientific instruments.

Several instruments were used to measure copepod concentrations and to map the dense copepod patches. Other instruments collected copepods and measured the temperature and salinity of the ocean. Scientists also temporarily tagged whales with acoustic transmitters (which the whales can't hear) and tracked their dives and movements with four hydrophone-equipped buoys.

For the first time, the scientists deployed autonomous underwater vehicles (developed by WHOI oceanographer Dave Fratantoni) with instruments that continuously recorded whale sounds.

"We're piecing together all the factors and conditions that come together to create these large aggregations of copepods," Baumgartner said.

Understanding the complex dynamics of the ecosystem "may give us an idea of where to look for other right whale habitats we haven't discovered yet," he said. It also will help scientists understand how those ecosystems can shift or be disrupted—especially by a changing climate.

"Given the right whale's low population," Baumgartner said, "if a change in the climate or the ocean caused the availability of copepods to plunge, right whales could go right down the tubes."

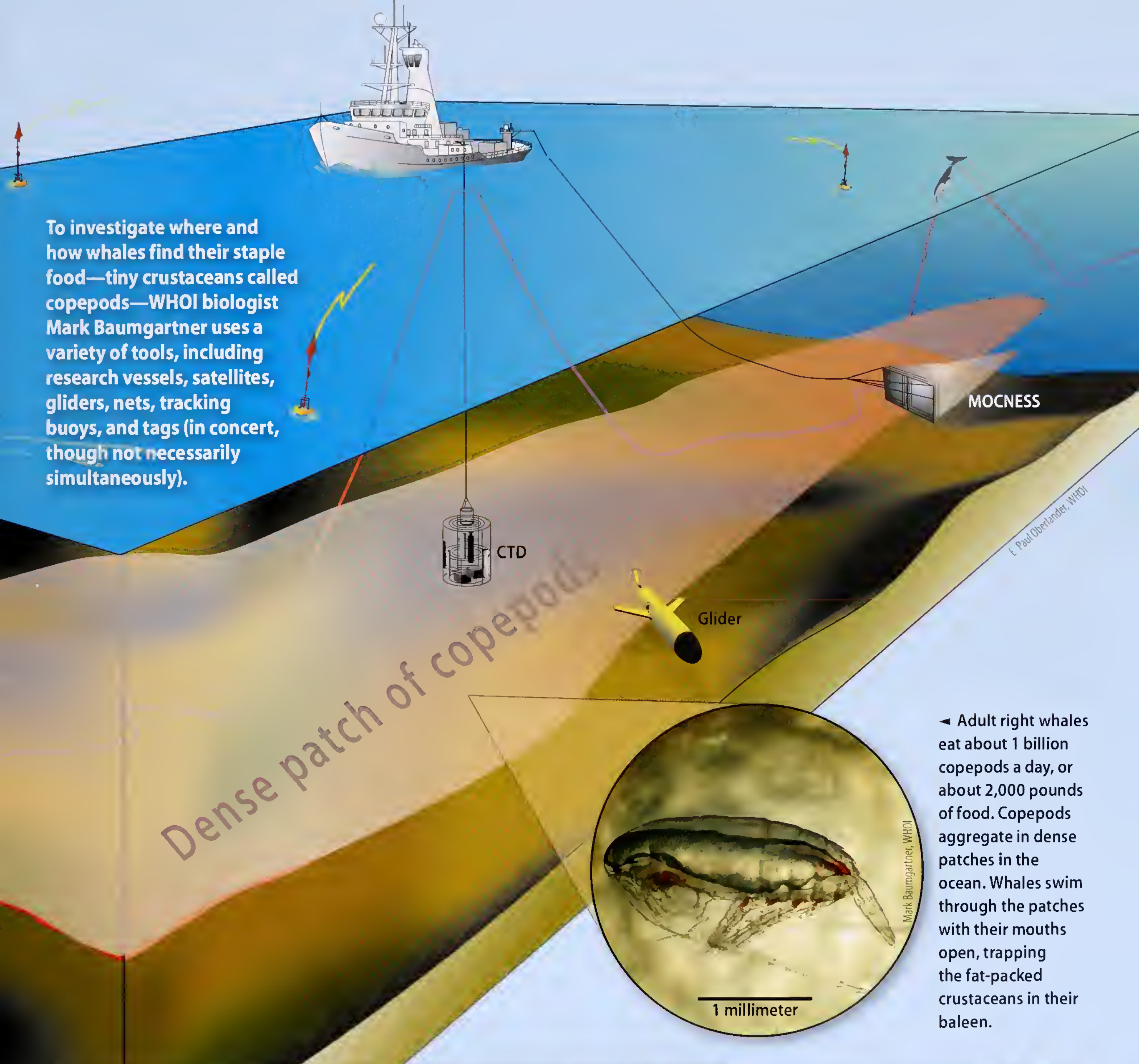
—*Amy E. Nevala*

The research was funded by the WHOI Ocean Life Institute Right Whale Research and Conservation Initiative and the National Marine Fisheries Service.

Courtesy of Mark Baumgartner

▲ To learn how whales feed, Baumgartner uses an 8-meter (27- foot) aluminum pole to gently place a tag on whales' backs. "After one to three hours, the tag comes off and floats to the surface, and we can pick it out of the water and download the data," he said. "We can then relate the whale's diving behavior to the abundance and depth of copepods."

To investigate where and how whales find their staple food—tiny crustaceans called copepods—WHOI biologist Mark Baumgartner uses a variety of tools, including research vessels, satellites, gliders, nets, tracking buoys, and tags (in concert, though not necessarily simultaneously).



◄ Adult right whales eat about 1 billion copepods a day, or about 2,000 pounds of food. Copepods aggregate in dense patches in the ocean. Whales swim through the patches with their mouths open, trapping the fat-packed crustaceans in their baleen.

Mark Baumgartner, WHOI

▲ MOCNESS (Multiple Opening and Closing Net and Environmental Sensing System) is towed behind ships. It uses nine nets to sample copepods at various water depths.

Amy Nevala, WHOI

▲ A CTD (for "Conductivity/Temperature/Depth") is an instrument that is lowered from a ship and towed behind it. It measures water temperature and salinity.

Mark Baumgartner, WHOI

▲ Gliders swim in the vicinity of whales for days at a time, gathering measurements of water salinity and temperature, and recording whale sounds.

What's wrong with this picture?

Healthy clams generally live beneath the sand.

These clams struggled to the surface to die.

They were killed by QPX: Quahog Parasite Unknown.

Farming—even shellfish farming—is like war: a constant struggle against invading hordes. On clam plots in the tidal waters of Cape Cod, the battle lines seem clearly drawn.

Inches below the sand, thousands of clams filter ocean water and grow big enough to eat in about two years. Above them, crabs sidle by hunting young, soft clams. Moon snails troop past like pale-purple golf balls, drilling into older clams and making pencil-tip holes. The slow-motion conflict plays amid waving fronds of seaweed or, if the tide is low, on wet sand flecked with tiny mud snails.

Cape Cod's $5 million shellfish aquaculture business has bloomed in recent years, in part because the natural threats to quahogs, or hard clams, seemed to be minor and manageable. But that was before a mysterious new disease—named QPX, for "Quahog Parasite Unknown"—began killing clams by the thousands.

QPX seemed to emerge from nowhere when it struck the clam plots of Provincetown, Mass., in 1993. Although the disease poses no threat to humans, it killed nine out of 10 clams in some plots and all but shut down clam farming in Provincetown. Since then, the disease has appeared across Cape Cod, in Duxbury, Mass., as well as in Virginia, New Jersey, New York, and Canada.

Shortly after the outbreak, Roxanna Smolowitz, a veterinarian at the Marine Biological Laboratory in Woods Hole, examined the sick clams under a microscope and identified QPX as the culprit. Although she could diagnose infected clams, she couldn't be sure that clams without signs of QPX were disease-free.

Now, a sensitive new genetic test developed by Rebecca Gast, a biologist at Woods Hole Oceanographic Institution, can detect QPX cells in clams, seawater, and sediment. The new test means Gast and her colleagues can study how QPX exists in its environment—something they could only guess about before. They're learning that QPX may normally spend its time peacefully decomposing dead seaweed, and that crippling the clam industry may simply be a side effect. Still, the virulent infections highlight a general problem that other aquaculture industries may one day face.

Courtesy of Capt. Andrew Cummings

◄ Capt. Andrew Cummings stands atop clams he and others dug out of their Wellfleet plots to quell a QPX outbreak last winter. Cummings estimated the removal claimed nearly 2 million clams.

"Red tide got the big attention this year," said Gast. But months after a red tide, or harmful algal bloom, has faded, shellfish clear the algal toxins and can be safely sold at market. "In terms of livelihood," she said, "QPX can be a bigger problem for shellfishermen—because it kills the clams."

QPX is an obscure, single-celled relative of slime mold that has both animal and fungal characteristics. It secretes a thick layer of mucus to ward off the clam's immune response. Other species related to QPX cause diseases in squid, octopus, abalone, and sea slugs.

Infected clams are weak, and their shells hang slightly open. Irritating sand lodges between the shells, and the sick clams work their way up to the seafloor. By this stage, the mucus is sometimes obvious on the edges of the shells, Smolowitz said, and the sound of the clams trying to close up is "like a million people grinding their teeth." The force of the grinding often chips the shell edges. Inside the clam are more telltale symptoms: tan nodules set apart from the healthy, pale-peach clam flesh.

Smolowitz has noticed that infections typically start at the base of the clam's

► Marine biologists Roxanna Smolowitz (left) of the Marine Biological Laboratory and Rebecca Gast of Woods Hole Oceanographic Institution examine tiny seed clams. Gast developed a new genetic test to detect QPX cells in clams, seawater, and sediments, giving scientists a way to learn more about how the organism infects clams.

Tom Kleindinst, WHOI

siphon. She and Gast think that's because of the way a clam's digestive system works. As the siphon sucks in seawater, chunks of rejected food particles collect at its base. That material (called pseudofeces, because it is periodically excreted but never goes through the gut) may act like an incubation chamber for QPX. When QPX does enter the clam's gut, it gets digested and can't cause an infection.

Before Gast developed her new test, people knew only that QPX spread directly from clam to clam, like flu in humans. Although QPX also infects wild clams, direct infection is especially dangerous for densely planted clam plots—"just like a crowded city is more prone to have sick people than a less-crowded city," said Bill Walton, an aquaculture specialist with the WHOI Sea Grant program and the Cape Cod Cooperative Extension.

The direct-infection model supported the idea that QPX was moving around the Eastern Seaboard in batches of tiny "seed clams" that farmers buy in bulk from suppliers. Gast's preliminary testing suggests QPX persists in many coastal waters, clinging to dead seaweed or riding in the sludge that collects on the backs of snails.

Smolowitz and Gast think clams may become infected when QPX reaches a critical threshold in the water. So their next step is to find out how much QPX it takes to make clams sick, and whether different strains of clams have different levels of resistance.

Smolowitz thinks that clams brought to the Cape from southern waters might have functioned as Trojan horses. These less hardy southern clams contracted the disease at a low threshold, and as they died, they may have raised QPX levels in the water high enough to make the native clams sick, too.

One of Smolowitz's experiments has already suggested as much. She grew clams from five parts of the Eastern Seaboard in both warm and cold waters. When southern clams grew in cold, Cape Codlike waters, they succumbed to QPX more often.

The idea makes sense: Clams accustomed to warm water might be weakened when forced to grow in chilly water. Or as winter approaches, their immune systems might shut down before the QPX organisms become inactive, giving the disease easy access, Smolowitz said.

With QPX turning up in so many locations, Gast said, "We're not going to be able to cure it. Keeping it below the level of infectivity is going to be important."

Some fishermen are turning to age-old tactics like crop rotation. Alternating clams with oysters might hold down the levels of disease in both crops.

Another approach uses the details of physiology that Smolowitz and others have painstakingly identified. QPX dies almost immediately when plunged in fresh water, so a rinse of seed clams could help make them safe.

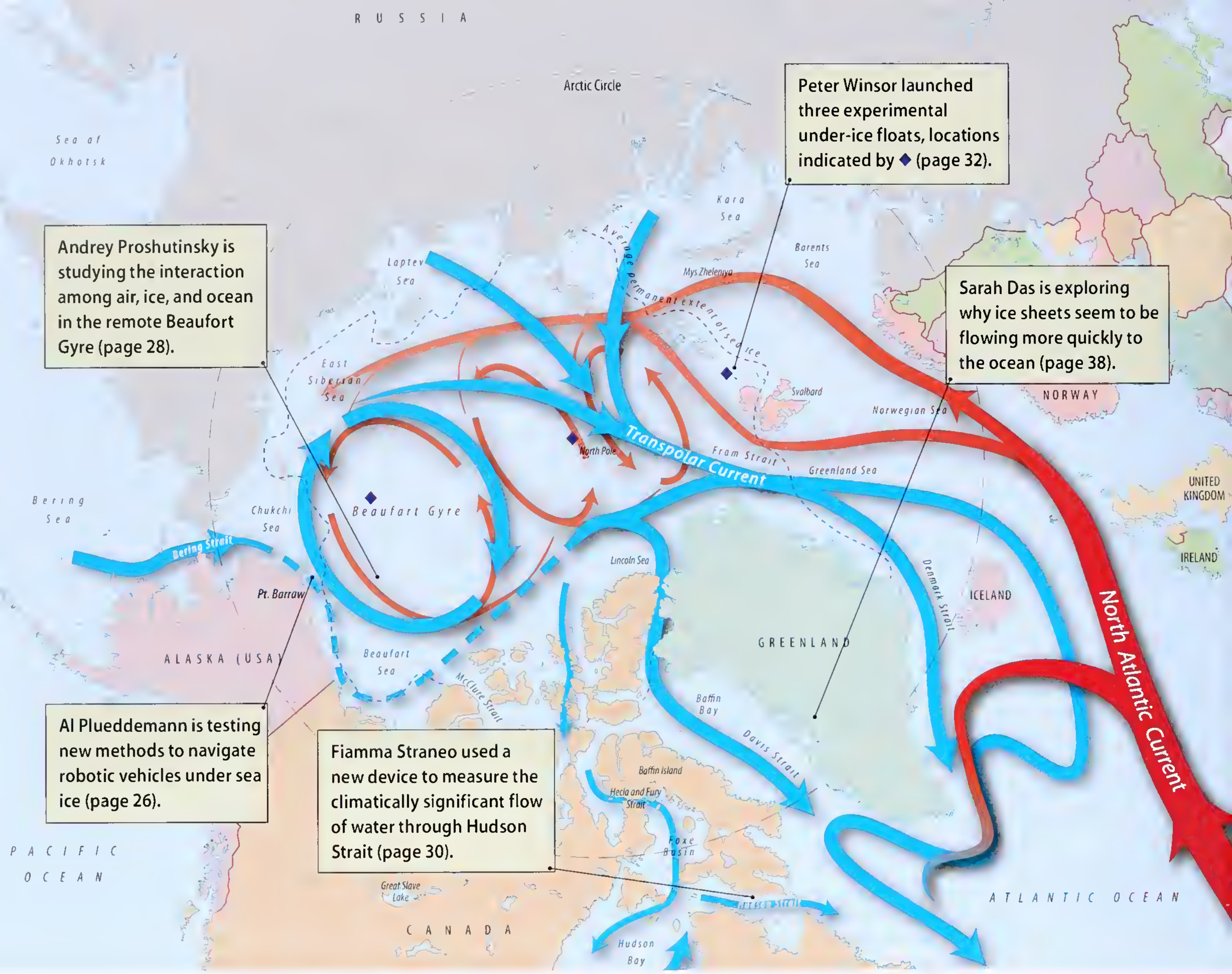
Other ideas include keeping plots cleared of seaweed, since it harbors QPX. Removing the nets that shellfishermen use to keep predators away from young clams may also keep seaweed from building up. And Walton is still experimenting to find an optimal density for growing clams—enough to turn a profit, but not so close together that the clams become stressed and weak.

Aquaculture is the fastest-growing segment of the fishing industry as wild stocks decline and the world appetite for seafood grows. Farming instead of fishing makes as much economic sense as ranching instead of hunting. But QPX is a reminder that the same pitfalls—overcrowding, reliance on a single crop, and susceptibility to disease—are waiting to be solved in the oceans as well.

"There's a joke about aquaculture, that you find out all the ways to kill something, and then you stop doing them," Walton said. Shellfishermen have already learned how to keep crabs, snails, and seagulls from robbing their plots. But for the moment, QPX remains on the to-do list.

—Hugh Powell

WHOI Sea Grant and the Northeastern Regional Aquaculture Center funded Gast's and Smolowitz's research. Tom Marcotti, Town of Barnstable shellfish warden, and Elizabeth Cushman, a WHOI summer student fellow, contributed to the study.



▲ Follow the water: Cold, relatively fresh water from the Pacific Ocean enters the Arctic Ocean through the Bering Strait. It is swept into the Beaufort Gyre and exits into the North Atlantic Ocean through three gateways (Fram, Davis, and Hudson Straits). Warmer, denser waters from the Atlantic penetrate the Arctic Ocean beneath colder water layers, which lie atop the warmer waters and act as a barrier preventing them from melting sea ice. Woods Hole Oceanographic Institution scientists have launched a variety of missions to explore how global climate change is affecting the Arctic, and how changes in the Arctic , in turn, could spill out and cause further climate change well beyond the polar region.

Is global warming changing the Arctic?

And will polar changes trigger climate shifts beyond the Arctic?

In 2005, the ice cap covering the Arctic Ocean shrank to its smallest size since researchers began keeping records a century ago. In the past five years, scientists reported that many Greenland glaciers are sliding faster to the sea and melting at their edges. Climate simulations indicate that the buildup of greenhouse gases in the atmosphere will accelerate melting.

Are these temporary phenomena or the first hints of long-term climate change? The answers are critical because the Arctic will not just feel the impacts of climate change, it will also cause a cascade of other global changes. As the Arctic goes, most scientists say, so goes the planet.

In the Arctic, the air, sea ice, and underlying ocean all interact in a delicately balanced system. To understand why, you have to follow the water.

It starts at the narrow Bering Strait between Alaska and Siberia, where cold and relatively less salty water from the Pacific Ocean enters the largely enclosed Arctic Ocean. In winter, frigid winds from the icy Alaskan interior blast over the shallow Chukchi Sea. The cold air freezes coastal

seawater into sea ice and then pushes it farther out to sea, leaving new pockets of seawater available for freezing. This is "the ice factory," which, in the process of manufacturing ice, also transforms the seawater left behind.

When seawater freezes, it releases salt into surface waters. These cold, salty waters become denser and sink, spilling over the continental shelf into the basin of the western Arctic Ocean. They create a layer known as a halocline (from the Greek words for "salt" and "slope"). Halocline waters lie atop a deeper layer of saltier, denser—and warmer—waters that flow into the Arctic from the Atlantic Ocean.

"The halocline provides a barrier that shields the sea ice cover from contact with deeper, warmer waters," said WHOI physical oceanographer Al Plueddemann. "This protects Arctic ice from melting."

Once in the Arctic Ocean basin, the water is swept into a mammoth circular current—driven by strong winds—called the Beaufort Gyre. Mighty Siberian and Canadian rivers also drain into the gyre to create a great reservoir of relatively fresh water. Winds trap this water in a clockwise flow, but periodically, the winds shift and the gyre weakens, allowing large volumes of fresh water to leak out. This is "the flywheel," said WHOI physical oceanographer Andrey Proshutinksy, and when it turns off, fresh water flows toward the North Atlantic.

The water exits the Arctic Ocean via several "gateways." It can flow through the Fram Strait, between northeast Greenland and Svalbard Island, and then branch around either side of Iceland. It can flow around the west side of Greenland through Baffin Bay and out Davis Strait. It may also flow through a maze of Canadian islands and out Hudson Strait.

These gateways are two-way: They also let in the warmer Atlantic waters that—if not for the halocline—could melt Arctic sea ice.

Melting sea ice has consequences. If the sea ice disappears, heat from the sun—which mostly reflects off white ice surfaces and back into space—instead would be absorbed by the ocean. This would further accelerate the warming of the Arctic. More warming means more melting: If the permafrost across the Arctic tundra melts, it could release vast reservoirs of methane, a greenhouse gas that can trap 10 times as much heat as carbon dioxide. If more Greenland glaciers melt, more water will pour into the oceans and raise global sea levels.

Melting sea ice also means more fresh water in the ocean, which could flood into the North Atlantic. That could disrupt a global system of currents, known as the Ocean Conveyor. The Conveyor brings warm, salty Gulf Stream waters northward, where they release heat to the atmosphere in winter and temper the North Atlantic region's climate. The waters then become cold enough again to sink to the abyss, propelling the underside of the Conveyor.

"Adding more fresh water to the North Atlantic could put a cap of lighter water over the denser, warmer water, blocking it from releasing its heat to the atmosphere and preventing it from sinking to drive the Conveyor," said WHOI physical oceanographer Fiamma Straneo. "Small changes in fresh water can induce large changes in our climate. It's something we need to measure, monitor, and understand. But it's easier said than done."

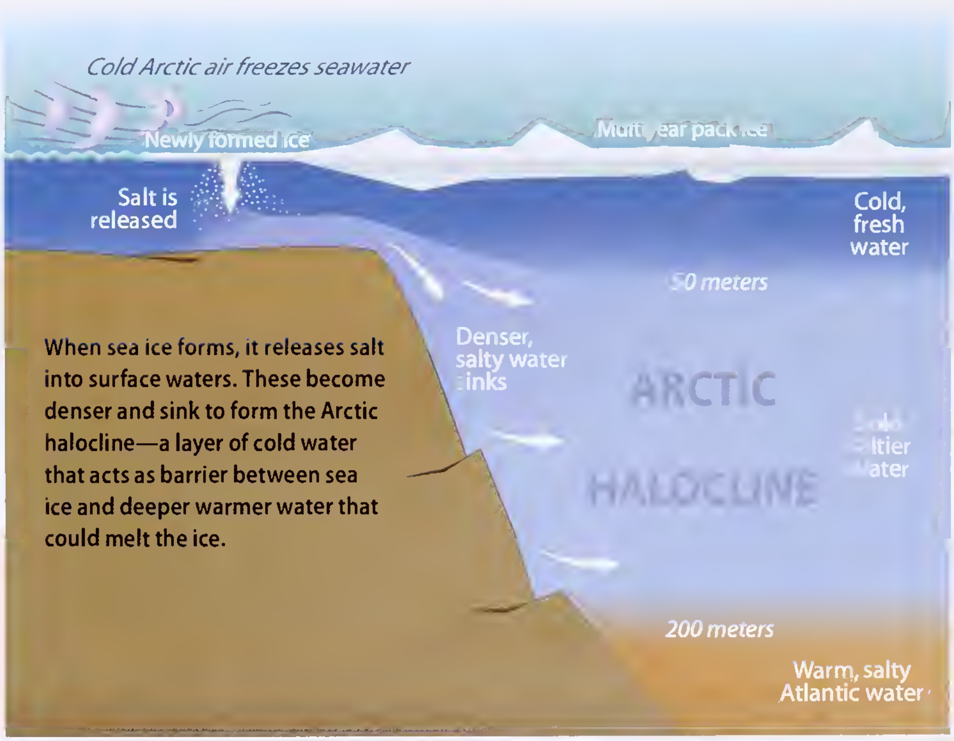
That is especially true in the Arctic, whose frigid, sunless winters, remoteness, and ice cover make expeditions difficult and expensive. The ice presents another barrier: It is difficult to build instruments that can penetrate it or survive it for long periods.

Enter Gary Comer, founder of the Lands' End clothing-catalog company and an avid open-ocean sailor. In 2001, while attempting to navigate the Northwest Passage in his yacht, Comer was stunned by the dearth of sea ice in the Arctic Ocean. Seeking answers, he contacted Woods Hole Oceanographic Institution.

The Comer Science and Education Foundation donated substantial support to the WHOI Ocean and Climate Change Institute, which used some of the funds to launch three ambitious Arctic projects—led respectively by Plueddemann, Proshutinksy, and Straneo. All involved designing, building, and field-testing high-risk, high-reward oceanographic instruments to help pull back the icy veil shrouding our understanding of the Arctic Ocean's role in our climate system.

On the following pages, we report on three expeditions in the summer of 2005 to explore "the ice factory," "the flywheel," and one of the "gateways."

—Lonny Lippsett



When sea ice forms, it releases salt into surface waters. These become denser and sink to form the Arctic halocline—a layer of cold water that acts as barrier between sea ice and deeper warmer water that could melt the ice.

Jayne Doucette, WHOI

Flying blind in the ice factory

Scientists test innovative technology to navigate vehicles under polar ice

This is Al Plueddemann's dream: He wants to push the envelope and fly a robotic vehicle into the wild blue under the polar ice cap.

North of Alaska lies a key region for understanding Earth's climate. In this place, huge volumes of sea ice are formed and, in the process, ocean water is transformed in ways that prevent the sea ice from melting.

"The problem is that these important transformations occur in water beneath the sea ice, so they are difficult to observe," said Plueddemann, a scientist at Woods Hole Oceanographic Institution. He wants to use autonomous underwater vehicles (AUVs) to go into these inaccessible areas of the ocean and observe the processes going on there. But that leads to another challenge.

AUVs navigate by sound. In the vast, dark, three-dimensional space of the ocean, AUVs maintain fixes on their position in three ways. Like people feeling their way through a dark room by touching a wall, AUVs keep in contact with the seafloor by "touching" it with sound waves, using an acoustic Doppler current profiler (ADCP). They also keep within listening range of acoustic beacons placed on the seafloor, which emit sound signals that can be heard 1 to 2 kilometers away. Finally, the AUVs can rise to the surface to get a Global Positioning Satellite (GPS) signal. With three methods of navigational reference (and a compass to keep it pointed in the right direction), AUVs usually don't get lost.

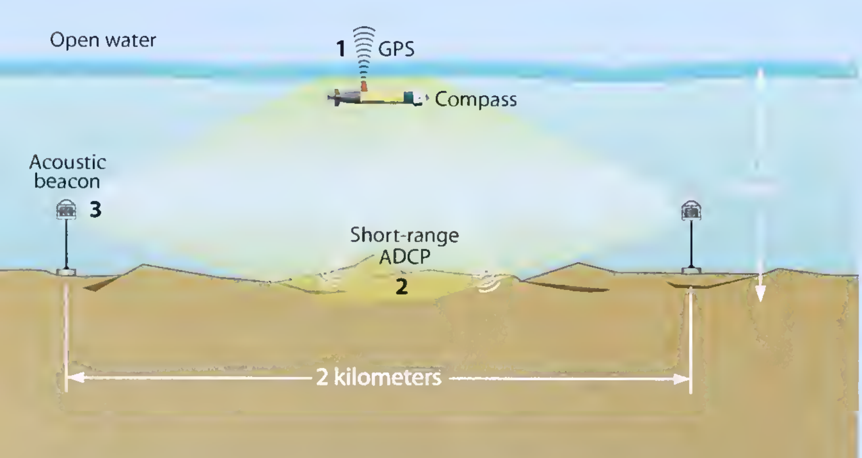
When AUVs move into deeper water, however, their ADCP signals can't reach the seafloor. And, under Arctic ice, it's difficult and expensive to set seafloor acoustic beacons every 2 kilometers.

"We have to stretch the box in which the AUV can navigate—horizontally and vertically—all at once," Plueddemann said. "And then we also have to deal with a lid on it—the sea ice—so we can't use GPS."

Plueddemann and colleagues in the WHOI Ocean Systems Laboratory installed an inertial navigation system (INS) into one of WHOI's Remote Environmental Monitoring Units (REMUS)—a portable, 100-pound, 6-foot, battery-powered AUV. The navigation system uses the vehicle's orientation, acceleration, and propeller turns to calculate an approximate position. In theory, an INS would allow AUVs to navigate via dead reckoning over longer distances between beacons. It's a bit of a technological trapeze act with no acoustic safety net.

With a grant from the WHOI Ocean and Climate Change Institute (through a gift from the Comer Science and Education Foundation), Plueddemann chose to field-test the new INS-equipped REMUS in a scientifically strategic locale—off Barrow, Alaska. Here, a confluence of circumstances conspires to create sea ice and, more important, to "transform" water so that it shields and protects the polar ice cap. Cold, rela-

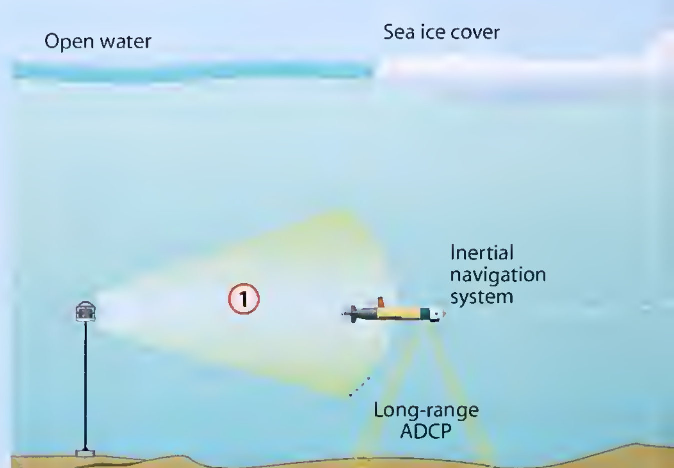
Navigating autonomous underwater vehicles (AUVs)



At present, AUVs typically locate their position in shallow water by three methods of navigational reference, using GPS at the surface (1); an acoustic Doppler current profiler (ADCP) to "touch" the ocean bottom (2), and signals from stationary acoustic beacons (3).

Jayne Doucette, WHOI

Stretching AUV navigation capabilities in the future



1) Near an acoustic beacon, the AUV has two navigational reference points: from the beacon and from the seafloor using its ADCP.

tively fresh water from the Pacific Ocean enters through the Bering Strait, flows across the shallow Chukchi Sea, and surges along the coastline off Barrow. Frigid winter winds whip off the Alaskan landscape, cooling Chukchi Sea waters all the way down to its shallow bottom, making it easier to form sea ice. The winds then blow the newly formed ice away, leaving open patches of cold water to create more ice.

"Scientists call this place 'the ice factory,' " Plueddemann said. "But it's also a 'Pacific water transformation factory.' "

When seawater freezes to form sea ice, salt is released into surface waters, which become denser and sink. This creates a pool of cold, salty water that flows into the Arctic Ocean basin, It spreads to form a layer called a halocline, which lies above an even saltier, denser layer of water originating from the Atlantic Ocean (see page 25). The halocline shields sea ice from contact with the significantly warmer Atlantic layer, which could potentially melt the ice and cause momentous climate changes well beyond the Arctic.

Plueddemann—along with WHOI engineers Greg Packard and Jeff Lord and WHOI postdoctoral fellow Andre

Al Plueddemann, WHOI

▲ WHOI engineers Greg Packard (right) and Jeff Lord deploy a REMUS underwater vehicle off Barrow, Alaska, where the formation of sea ice "transforms" waters from the Pacific and makes them saltier and denser.

Shcherbina—went to Barrow in the summer of 2005 to test the new INS-equipped REMUS initially in less risky ice-free summer waters.

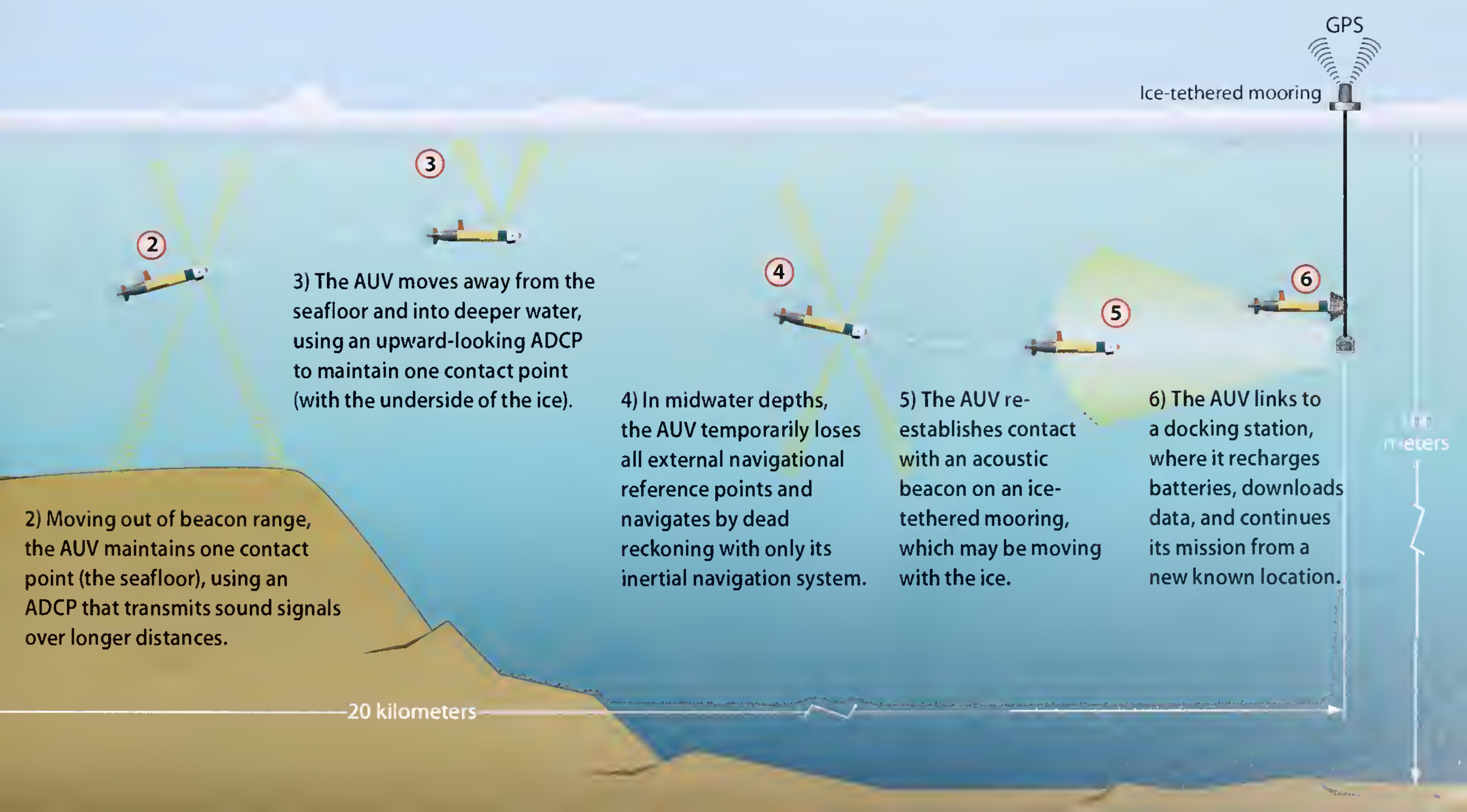
Barrow is 340 miles north of the Arctic Circle. It has a population of about 4,500, mostly Inupiat, but no harbors or docks. So the team had to launch their chartered 30-foot aluminum boat from the beach. Temperatures in August were near freezing.

From the boat, they launched an INS-equipped REMUS with sensors that successfully collected the first detailed measurements of water temperature and salinity and currents off Barrow. But they were not surprised that the field tests revealed subtle, unanticipated glitches. For example, the INS's noisy power supply was too close to the ADCP and interfered with its bottom-tracking acoustic signals.

At the same time, however, the experiment also "changed our view of how under-ice operations could be conducted," Plueddemann said. The INS tracked well enough in shallow water to keep REMUS on its intended course. Assisted by just one navigational reference point—bottom-tracking—it appears feasible that REMUS could complete a 20- to 30-kilometer round trip between beacons. To allow AUVs to maintain contact with the bottom in deeper water, the team is integrating a new ADCP that uses lower-frequency sounds waves, which transmit over longer distances.

The next hurdle is to get AUVs to home into moving (rather than fixed) acoustic beacons. The researchers' vision is a network of moorings—locked into sea ice and stretching across the ice cap—with beacons hanging down into the ocean and AUVs happily hopping among them.

—Lonny Lippsett



The flywheel of the Arctic climate engine

Remote Beaufort Gyre expeditions reveal clues to climate change

The bottom line is that the top of the world will play a decisive role in determining how Earth's climate changes. Global warming already may be tipping the Arctic's delicately balanced system of air, ice, and ocean and poising it to trigger even larger, more widespread climate changes.

A key component of the Arctic climate clockworks is the Beaufort Gyre—a bowl of cold, icy, relatively fresh waters north of Alaska that is swept by prevailing winds into a circular swirl larger than the Gulf of Mexico. WHOI physical oceanographer Andrey Proshutinsky calls it "the flywheel of Arctic climate."

The gyre accumulates fresh water created when ice melts. More fresh water drains into it from big northern rivers. Winds typically corral this huge freshwater reservoir, but when they periodically diminish, the gyre weakens, vast volumes of trapped fresh water leak out, and climate conditions shift.

Recent evidence indicates that this accumulation-and-release mechanism may be tipping out of balance, but scientists can't say for sure. The Beaufort Gyre is one of the least-studied bodies of water on the planet. Researchers haven't gained sufficient access to this cold, icy, remote, and dark-for-half-the-year region to learn how it operates. They haven't been able to stay long enough to monitor how it shifts naturally over seasons, years, or decades. In many ways, the ice-covered Beaufort Gyre remains a big white black hole.

In 2003, the Office of Polar Programs at the National Science Foundation (NSF) funded Proshutinsky to lead an experiment to investigate the Beaufort Gyre. Joining other U.S., Canadian, and Japanese researchers aboard the Canadian Coast Guard icebreaker *Louis S. St. Laurent*, WHOI researchers deployed an array of newly developed instruments to collect data on the environment above, below, and within the floating icepack.

◄ The red sphere atop a mooring is recovered after a year submerged in the Arctic Ocean.

The WHOI team deployed three moorings in the gyre, with lines stretching between a seafloor anchor 3,800 meters (12,470 feet) deep and a flotation package 50 meters (164 feet) below the ice. Each line held instruments to measure currents, water temperature and salinity, sea ice draft, and sea surface heights. Researchers also collected hundreds of water samples at sites between the moorings, measuring temperature and salinity, as well as chemical tracers to determine the sources of water in the gyre. The expedition allowed researchers, for the first time, to measure conditions in the Beaufort Gyre over a full year.

"There are so many interactions between the ice, ocean, and atmosphere, and small changes can lead to big changes," Proshutinsky said. "Here is an example: A warmer Arctic atmosphere can lead to less sea ice. That means more ocean is exposed in winter, absorbing solar radiation instead of reflecting it, as sea ice does. That warms the region further and melts more ice, which leads to more fresh water in the gyre."

Fresh water is a critical ingredient for two reasons. Because it is lighter than the saltier, warmer waters that infiltrate the Arctic Ocean from the Atlantic, it lies atop the warmer waters and acts as a barrier preventing them from melting the sea ice. In

Photography by Chris Linder, WHOI

▲ **A science party from CCGS *Louis S. St. Laurent* installs instruments on Arctic sea ice that monitor ocean, ice, and atmospheric conditions and transmit data daily via satellite. From left to right: WHOI engineer Kris Newhall jumps across a melt pond; Rick Krishfield (WHOI) and Doug Sieberg (Institute of Ocean Sciences, Canada) auger a hole in the ice to install an Ice Mass Balance Buoy; Newhall, Krishfield and John Kemp of WHOI assemble a tripod to deploy an Ice-Tethered Profiler; ship's boatswain Robert Taylor turns away from wind and snow blown up by a helicopter returning to the ship to retrieve more equipment.**

addition, more fresh water leaking out of the Arctic can also block saltier, warmer waters in the North Atlantic from releasing their heat to the atmosphere, which tempers winters in North America and Europe.

Initial NSF support ended with recovery of the moorings in 2004. But to continue monitoring this climatically sensitive region, the WHOI Ocean and Climate Change Institute stepped in to provide funds to redeploy the three moorings and establish the Beaufort Gyre Observing System.

In 2004, the WHOI team also deployed a prototype new instrument, the Ice-Tethered Profiler (ITP). Designed and built by WHOI scientists and engineers—John Toole, Rick Krishfield, Ken Doherty, Keith von der Heydt, Terry Hammar, and Don Peters—the ITP has a small yellow surface capsule that dangles an anchored 800-meter (2,265-foot) line through a hole in an ice floe. An instrument travels up and down the line daily, measuring water pressure, temperature, and salinity. Data are transmitted via satellite to WHOI, along with a GPS location of the instrument on the drifting floe. The ITP has enough battery power to last for three years, barring a breakup of the ice floe or polar bear vandalism.

To deploy the ITP, a WHOI team of Krishfield, John Kemp, and Kris Newhall landed by helicopter on the ice and drilled a 25-centimeter (10-inch) hole in an ice floe 4 meters (13 feet) thick. A rifle-toting seaman watched for polar bear. The ITP was clustered with another buoy developed by U.S. Army researchers, which monitors atmospheric conditions and changes in the ice. The WHOI ITP sent back 244 profiles of the Arctic Ocean before it stopped transmitting in September 2004. "We think the ice broke," Krishfield said.

The successes of these expeditions helped persuade NSF to resume funding to maintain the Beaufort Gyre Observing System through 2008. On the summer 2005 cruise, WHOI researchers installed two new ITPs, both of which were still returning data in December.

"Every morning at 8 a.m., I hear their modems click on in my office, and I know they are transmitting data from the Arctic back home," Krishfield said. "Eventually, we'd like to distribute 20 to 30 ITPs to capture what's going on in the ocean, air, and ice throughout the Arctic Ocean."

The 2005 expedition also added a fourth mooring, forming the last corner of a box of moorings around the gyre. Kemp led the arduous efforts to recover and redeploy the other three moorings in waters choked with mammoth ice rafts.

"Each instrument contains a year's worth of data," said WHOI researcher Chris Linder. "It is an expensive instrument in itself, but with that data, it is now priceless. The data will tell a story. More than mere numbers, they are like the pieces of a puzzle that waits to be completed."

With continuous monitoring over five years, the Beaufort Gyre Observing System should provide crucial clues to help scientists unravel the critical factors that change Arctic conditions naturally, or that may be changing them in response to global warming caused by humans.

"Are the changes we're seeing catastrophic, or just a bump in the road?" Krishfield asked. "Is the flywheel broken, or is this a temporary phase in a natural cycle?"

—Lonny Lippsett

◄ **WHOI researchers grapple with a moored profiler, an instrument that travels up and down a mooring line several times a day, measuring ocean temperature and salinity.**

A sentry at the Atlantic gateway

◄ **The last to go into the water is a big red flotation sphere atop a mooring 180 meters (590 feet) long that collected the first detailed measurements of water flowing out of Hudson Strait. Changes in the outflow can have an effect on climate in the North Atlantic region.**

Experimental mooring monitors water flow through Hudson Strait

Here's an easy recipe to change Earth's climate: Just add more fresh water to the North Atlantic Ocean.

In this oceanic part of the world lies a critical—and sensitive—component of the heating and plumbing system that regulates the planet's climate. Messing with it is like tampering with the thermostat in your house.

Warm, salty, equatorial waters flow via the Gulf Stream to the North Atlantic. In winter, they confront cold air and release heat to the atmosphere, making winters in North America and northern Europe milder. The waters—still salty and now colder—become denser and sink to propel a global system of currents called the Ocean Conveyor.

Adding fresh water throws a monkey wrench into the system. It is much lighter than, and floats above, saltier water. The fresh water can form a cap that can block the deeper warm waters from surrendering their heat and that can slow down the Conveyor. Geological evidence has shown that this has happened many times in the past and caused significant climate changes.

Looming over the North Atlantic is the Arctic region, a large reservoir of relatively fresh water. It includes the Arctic Ocean and major Arctic and subarctic inland seas such as Hudson Bay. The region is filled with sea ice, which releases salt from seawater when it forms. The salt sinks, leaving fresh water at the surface. In addition, innumerable rivers drain precipitation over the continents into the Arctic. The fresh water is funneled out of the eastern end of the Arctic region through several small straits.

"Not surprisingly, then, climate scientists are very interested in monitoring these straits that act as freshwater gateways to the North Atlantic," said WHOI physical oceanographer Fiamma Straneo. "We have evidence that changes are happening upstream—in the rivers, in the sea ice, in the Arctic Ocean—but we do not know how these changes are affecting the freshwater discharge to the Atlantic, which is crucial if we are to understand our changing climate."

Straneo set sight on one gateway, Hudson Strait, which shunts large amounts of fresh water accumulated in Hudson Bay into the Labrador Sea. No one had ever measured or monitored Hudson Strait before, because it lies in a remote region, full of swift, strong currents, sea ice, and icebergs that are daunting for researchers and hell on instruments. Straneo needed funds, instruments that could endure the harsh environment, and a ship to get her there.

The funds came from the WHOI Ocean and Climate Change Institute, through a grant from the Comer Science and Education Foundation, to deploy a mooring in Hudson Strait. "This type of project wouldn't be easily funded by a government agency at this stage, because the risk is large," Straneo said.

Next, she assembled a variety of instruments that measure current velocities, water temperature and salinity, and ice thickness. The instruments would be attached to a mooring line anchored to the seafloor that would extend 50 meters (164 feet) below the surface. Still, she needed critical measurements from those last 50 meters, where much of the fresh water flows.

"But if we put an instrument up there, sea ice or icebergs would surely sweep it away," Straneo said.

To get around this obstacle, WHOI engineers Dan Frye and Steve Liberatore designed and built a new instrument called the Arctic Winch. Housed on the mooring's top flotation sphere, the winch periodically unspools a float with a number of sensors, which rises to the surface while collecting data.

"When it hits sea ice or the surface," Straneo said, "it is programmed to come back down immediately. So it gets measurements up to the surface, without spending time there waiting for ice to get hold of it."

With instruments and funds in hand, Straneo now needed to find a ship that would take her to an area where few ships go. She fostered a collaboration with Canadian scientists conducting research in Hudson Bay aboard the Canadian Coast Guard icebreaker *Pierre Radisson*. They agreed not only to take her, but also to deploy two supporting moorings to get better measurements of the freshwater flow across Hudson Strait.

In August 2004, Straneo and WHOI engineer Jim Ryder flew to Puvirnituq, a small Inuit village on Hudson Bay in Nunavik, Quebec's Arctic region, to rendezvous with the icebreaker. Waiting for the ship,

they spent a day talking to the locals who shared stories of caribou crossings, fishing and hunting on ice, and the difficulties that Inuit communities are experiencing as they transition to a less nomadic way of life.

"Not many people visit these isolated villages," Straneo said, "so people are curious and eager to talk. There is no road access to this region and necessary goods are brought in by ship only two times a year."

When the icebreaker arrived, Straneo and Ryder flew aboard by helicopter. While the Canadians conducted their research, Straneo anxiously waited her turn. In the Arctic, something—often bad weather—can always arise at the last minute to ruin the best-laid plans.

With the WHOI mooring gear ready on deck, the *Radisson*'s captain was notified that 40 Inuits were stranded on Nottingham Island some 200 miles away. If the ship turned around straightaway, there would have been no time to come back to Hudson Strait. Luckily for Straneo, the captain ascertained that the Inuits were in no immediate danger, so they proceeded with deployment. It was a sunny, warm day, and a few icebergs calmly drifted down the strait.

With her instruments in the water, Straneo returned to WHOI. The wait seemed eternal.

"You don't know if the instruments are working, or even if the mooring is still there until you get back one year later," she said. "It is quite nerve-wracking."

In September 2005, Straneo and the *Radisson* returned to Hudson Strait. "Few things can beat the excitement of spotting the large red flotation sphere rising to the surface after we released the mooring from its anchor," she said.

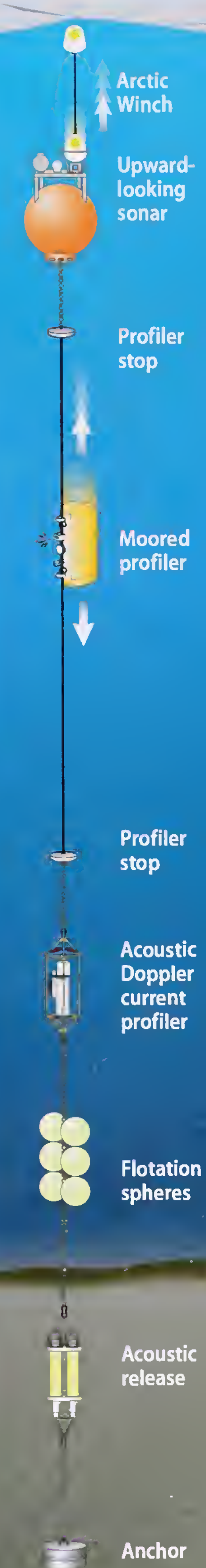
The Arctic Winch had worked for the entire year, though it had difficulties reaching the surface—probably because of strong surface currents that sometimes exceeded 5 knots. With the data in hand, the winch can now be improved for future deployments. And it took crucial measurements from those key 50 meters—a big success.

"For the first time," Straneo said, "we will be able to calculate the Hudson Strait freshwater outflow. The next questions are, 'Is it changing? How? Why?' "

—Lonny Lippsett

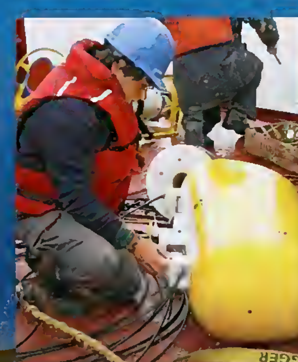
A mooring to work under the ice

WHOI oceanographer Fiamma Straneo deployed a mooring in the ice-covered Hudson Strait to measure the flow of water through this climatically significant gateway to the Atlantic Ocean. Anchored to the seafloor 180 meters (590 feet) deep, the mooring line held a variety of instruments, including an experimental device called the Arctic Winch to obtain critical measurements in the top 50 meters (164 feet), where less-dense fresh water flows just below the ice.

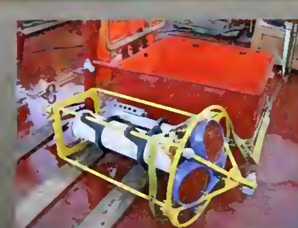


The Arctic Winch, atop a red flotation sphere, periodically unspools a float with sensors to collect data as it rises toward the surface. It comes back down immediately when it hits ice or the surface, so that sea ice or icebergs don't sweep it away.

An upward-looking sonar measures the thickness of ice flowing over the mooring.



Straneo recovers a moored profiler, an instrument that moves up and down the line every two hours, measuring water temperature and salinity between 50 and 150 meters (164 and 492 feet).



An acoustic Doppler current profiler uses sound waves to measure current speeds and directions.

Illustration by Jayne Doucette, WHOI; photos courtesy of Fiamma Straneo, WHOI

Arctic floats drift for months beneath sea ice, gathering data on ocean waters and transmitting them via satellite to scientists on shore. If the floats rise and encounter thick ice, their hardened antennae can withstand repeated impacts, and they are programmed to sink to a shallow depth and try again (and again) to find areas with thin or no ice.

Jayne Doucette, WHOI

Under-ice floats offer a 'breakthrough'

New instrument proves its mettle in an icy ocean

The Arctic Ocean, home to fierce winds, punishing temperatures, and thick sea ice, is no place for wimpy people—or machines. So when WHOI physical oceanographers Peter Winsor and Breck Owens set out to explore the largely unknown currents beneath the polar sea ice, they had to design an instrument with true grit.

"We needed the ultimate Arctic machine: intelligent, tough, and durable," Winsor said.

In recent years, oceanographers have employed torpedo-shaped instruments called floats that drift, nose pointed up, at various depths through the oceans while measuring water temperature and salinity. The floats are programmed to rise to the surface periodically and send data via satellite antenna to scientists on shore.

More than 2,000 of these floats are now dispersed to collect data over wide swaths of ocean territory for many years. Similar floats could work beneath the ice, but scientists have struggled to figure out how the floats would surface in ice-covered waters to transmit data.

Over the years, Owens has seen several proposals to overcome this barrier. They have included systems to give floats the capacity to melt ice, or devices that reflect sound signals off ice.

"But there are just too many things that can go wrong with complex designs," Owens said. "Our mantra was: the simpler, the better."

The floats he, Winsor, and WHOI engineers developed are smooth-sided and free of external machinery that could snag on ice. Next the scientists added toughness—particularly in the antenna, which is made of hard polyurethane that can withstand repeated impacts against the hard underside of sea ice.

Finally, they incorporated the "intelligence." When the float rises and encounters ice, it is programmed to simply sink to a shallow depth and try again (and again, up to 100 times). Eventually it rises in an ice-free area, or in narrow cracks called leads between sea ice.

"Bounce, bounce, bounce—the float antenna knocks against the underside of the ice," Winsor said. "It knows it should go back down, wait awhile, then test again for open water."

This summer, Winsor deployed three experimental floats into ice-clogged waters during a seven-week voyage across the Arctic Ocean aboard the Swedish icebreaker *Oden*. Though the floats were launched simply to see if they would work, Winsor is basking in their apparent success. This fall, back at WHOI, he and Owens have received e-mails from the floats every few days or weeks, as the floats find open water to surface and get in touch. (They have been corresponding less frequently as winter ice builds in the Arctic).

"It's like Christmas," Winsor said in mid-November, one day after the third float he deployed in heavy ice near the North Pole finally communicated with WHOI scientists. "It told us, in its own float language, 'Here I am, and here's the data I've collected so far.' "

Winsor and Owens are now working on proposals that could eventually seed the Arctic with floats. "Imagine what we could learn if we could have many of these roaming around the Arctic Ocean," said Winsor, who is a WHOI Ocean and Climate Change Institute fellow.

Additionally, they want to tweak their technology to include, for example, two-way communications that would give scientists the ability to modify the floats' missions from shore.

Winsor said the floats won't replace scientists on icebreakers visiting the Arctic, but will allow year-round research in a remote region where for months on end it is simply "too dark, too icy, too dangerous, and too cold" for even the toughest scientists.

"We joke that we've developed these floats because we're just jealous of oceanographers who work in the tropics," he said. "We say our ultimate dream is to create something that lets us sit on the beach with our laptops and collect data while the Arctic snow flies."

—*Amy E. Nevala*

The National Science Foundation's Office of Polar Programs funded this research.

Peter Winsor, WHOI

◄ WHOI scientist Luc Rainville, on the Swedish icebreaker *Oden* in August, prepares to test an experimental float designed for under-ice operations in the Arctic.

Institution receives surprise bequest

Claudia S. Heyman

A young woman who had been largely anonymous to the oceanography community has bequeathed a $14.5 million gift to Woods Hole Oceanographic Institution, the second- largest gift in the Institution's history.

Starting in 2006, four WHOI scientists will be chosen for annual fellowships to be named for Claudia S. Heyman, who listed the Institution in her trust before she died Nov. 13, 2004. She was 35.

The Institution's largest donation—a $28 million anonymous gift given in 2002—was used in part to fund four Ocean Institutes at WHOI. With the new funding from the Heyman fellowships, the Ocean Life Institute, the Ocean and Climate Change Institute, the Coastal Ocean Institute, and the Deep Ocean Exploration Institute will each select additional scientific fellows based on their leadership, their interest and ability to participate in interdisciplinary research, and their public outreach and communication skills.

Why Heyman left the money to WHOI remains a mystery, said Dan Stuermer, the Institution's director of development. "We know that at some point she either visited or read about WHOI and did some research about our scientists' work," Stuermer said. "We surmise that she was fascinated by the place."

Heyman, a native of Tulsa, Okla., who was living in Boston when she died, served on the board of her family enterprises and retained interests in several privately held oil and gas corporations, said her attorney, Paul F. Zerola.

He described her as an art enthusiast, avid reader, and a benefactor of animals who owned seven cats and a black Labrador named Hummer. "She cared deeply for her community and devoted much of her time and energy to humanitarian and charitable causes, and she constantly urged others to do the same," Zerola said.

Tom Kleindinst, WHOI

▲ A one-week crash course in oceanography for journalists.

The write stuff

For the sixth consecutive year, WHOI hosted a group of journalists for a weeklong fellowship program—more like a 40-hour crash course in ocean science. The September program included lectures, laboratory tours, field trips, and meetings between journalists and scientists. WHOI biologist Heidi Sosik (above left) shows off an instrument called the Imaging Flow Cytobot to (from left) Paul Thacker of *Environmental Science & Technology*, Mary Hoff (freelance), Lisa Strong-Aufhauser of Strong Mountain Productions, Gerald Rising of *The Buffalo News*, Jeanna Bryner of *Scholastic Science World*, and Kathleen Schmitt of Earthwatch Radio.

In October, the Institution awarded its second Ocean Science Journalism Awards, which recognize "journalistic excellence that advances public understanding of the oceans." Beth Daley and Gareth Cook of *The Boston Globe* were honored for their four-part series "Sea Change: The New England Fishing Crisis." Paul Kennedy of the Canadian Broadcasting Corporation won for his eight-part radio series "Learning from the Oceans."

Distilling an education

Byron Pedler (right) spent long hours this summer extracting and purifying compounds from dolphin fat, like a laborer in an 18th-century tryworks. Instead of boiling vats and flensing knives, his tools were glassware, solvents, and mass spectrometers. His end product was tiny amounts of hydrocarbons, rather than whale oil.

Pedler, a 2005 summer student fellow, worked with postdoctoral fellow Emma Teuten and Associate Scientist Chris Reddy of the Marine Chemistry and Geochemistry Department to determine concentrations of a brominated hydrocarbon compound in dolphin blubber. Once thought to be a contaminant, the hydrocarbon is now believed to be a natural component of dolphin food.

Since the late 1950s, the WHOI Summer Student Fellowship Program has provided a rich opportunity for research experiences to talented undergraduates interested in the ocean. Fellows in the program pursue an independent research project under the guidance of a member of the scientific or senior technical staff. To date, 984 students have participated in this program.

Tom Kleindinst, WHOI

▲ Byron Pedler examines curious compounds found in dolphins.

Bird's Eye View

▲ The Stanley W. Watson Laboratory (foreground) and the Marine Research Facility (background) provide new offices and laboratories for more than 90 WHOI employees.

WHOI opens new research facilities

For the first time in 15 years, the Woods Hole Oceanographic Institution has added significant office and laboratory space to its Quissett Campus. This fall, scientists, technical staff, and students started moving into more than 67,000 square feet of new space, a 25 percent increase in the Institution's scientific facilities.

The additions are the 31,950-square-foot Marine Research Facility and the 35,570-square-foot Stanley W. Watson Laboratory. Other improvements have also been made around campus.

More than 90 members of the Institution staff are moving from labs in the village of Woods Hole and other parts of the WHOI Quissett Campus, and all researchers should be in their new labs by the end of 2005. The new buildings will be officially dedicated in spring 2006.

"It's like a different institution," said ecologist Jesús Pineda, who now has twice as much lab and office space as he did in the basement of the Redfield Building. "There are many places to meet people and have discussions, so we talk more about our projects."

For nearly a decade, WHOI has been attracting specialists in marine mammal and ecological research, but those scientists have been spread out in four different buildings. The new Marine Research Facility houses almost all of these researchers in one setting that is better-suited to their needs—with more room, large freezers, medical-style imaging equipment, and facilities for dissection and necropsies.

"Scientists designed their own spaces from the ground up," said biologist Scott Gallag-

Tom Kleindinst, WHOI

▲ Bill McKeon (left), WHOI's director of shore operations, reviewed blueprints with a construction project manager. Campus planners, contractors, and scientists worked together to design the new facilities, including the CT scan and necropsy suite in the Marine Research Facility (center). Marine chemist Dan Repeta (right) and other researchers began moving into their new labs this fall.

er. "It will let us do things like developing large instruments and optical systems that we couldn't do before."

The Institution's master planning committee also saw a need to pull scientists together in the burgeoning field of biogeochemistry, which investigates the chemical interactions of living things with rocks, sediments, seawater, the seafloor, and hydrothermal vents.

"We are on the verge of understanding how the chemistry and physics of the ocean and the atmosphere influence, and are influenced by, biological processes," said Jim Luyten, WHOI Executive Vice President and Director of Research. "Microbiologists, geochemists, and geologists were spread out in different buildings and on different campuses. We needed to do something to enhance opportunities for interdisciplinary interaction and stimulate work on this leading edge of ocean science."

"My old lab was split between two floors," said Katrina Edwards, a biogeochemist from the Marine Chemistry and Geochemistry Department. "The microscopes and molecular tools were downstairs, the lab and offices were upstairs, and some were in a trailer. We constantly had to run from one to the other. Now we are all in one lab."

The $60 million campus redevelopment project has been under way since 2001, spurred by internal and external reviews of the Institution that found laboratories to be overcrowded and not necessarily fit for larger modern instruments. The research staff has been growing steadily for years, but no science-related construction had been undertaken since the expansion of Clark Laboratory in 1990.

Construction of a ring road—to give the Institution more of a campus feel and to make it safer for pedestrians—and other infrastructure improvements began in 2003. The Blake Building in the village of Woods Hole—home to the Deep Submergence Laboratory—was completely renovated in 2004.

More than $9 million was spent to modernize the physical plant, including new electrical systems to reduce the impact of Cape Cod's frequent power surges and outages; new energy-efficient boiler and chiller systems to provide heat and air conditioning; and new wastewater treatment facilities to clean laboratory and sanitary waste and reduce the Institution's impact on local marshes and coastal waters.

Excavation and construction of the new buildings began in the spring of 2004, aided by more than $15 million in donations to the Institution's comprehensive fundraising campaign and by low-interest loans through the federal Higher Education Finance Administration.

"Your environment affects how you get your work done, and we wanted to create a more collegial setting," Luyten said. "We now have a world-class campus that reflects the quality of the science being done here."

The redevelopment of WHOI facilities continues as 11,000 square feet are added to the McLean Laboratory to expand the seafloor sample storage facility and the world-renowned National Ocean Sciences Accelerator Mass Spectrometry facility. And campus planners have just held their first meeting to decide how to renovate the vacated space in the Redfield Laboratory to better accommodate biology researchers moving from more crowded labs.

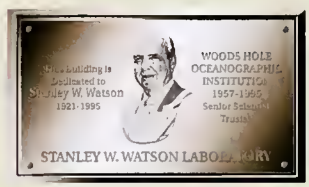
—Mike Carlowicz and Kate Madin

The new 35,570-square-foot Stanley W. Watson Laboratory

Biologist, businessman, benefactor

Institutional buildings are usually named after a person for one of two reasons: the namesake has achieved great things on behalf of the institution, or he or she is a generous benefactor. Stanley Watson was both to the Woods Hole Oceanographic Institution.

Watson, who died in 1995 following a 35-year career at WHOI, was a microbiologist whose research interests foreshadowed the cross-disciplinary field of biogeochemistry. He was instrumental in uncovering the importance of bacteria in ocean food webs and in the nitrogen cycle.



He collaborated with John Waterbury, now a senior scientist in the Biology Department, in a momentous discovery. On a 1977 cruise in the Arabian Sea, he found extremely small, previously unknown photosynthetic cells in seawater. They turned out to be one of the most numerous organisms on the planet: the cyanobacteria *Synechococcus*.

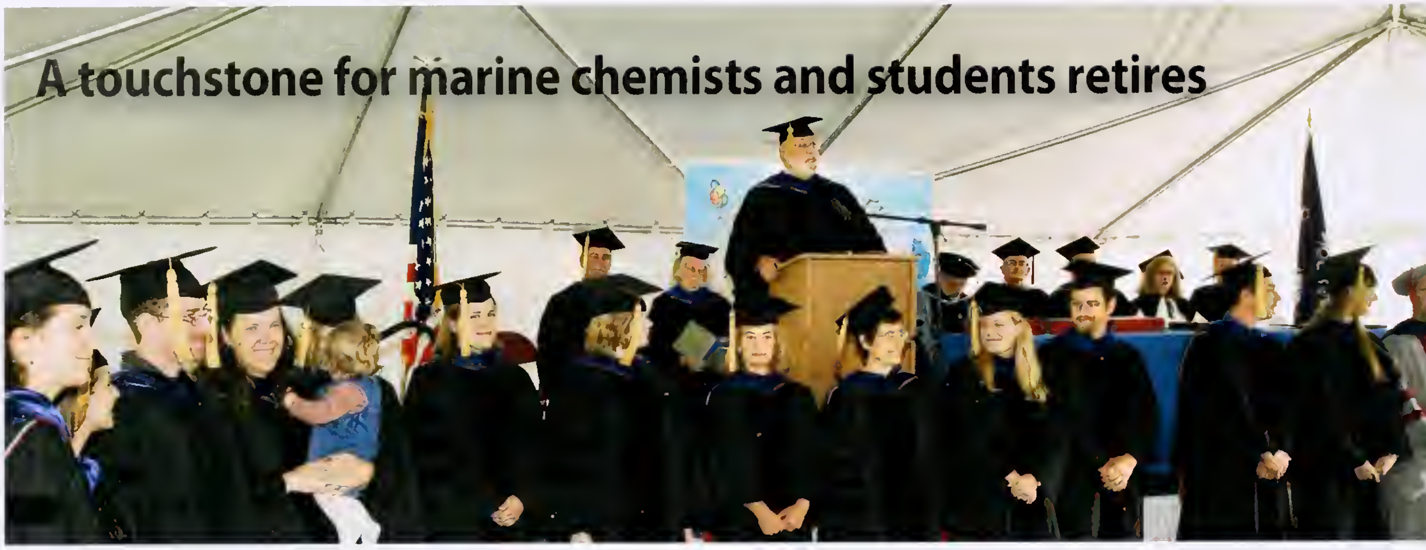
Watson also refined and patented a test for bacteria in seawater, using an extract from the blood of horseshoe crabs that reacts with toxins that bacteria release. In a successful second career as head of Associates of Cape Cod, Watson and company produced that extract—limulus amoebocyte lysate (LAL)—which is used by hospitals and medical device producers worldwide to detect bacterial contamination and ensure safe products. Proceeds from the company formed the basis for the Watson Foundation, which has supported research and education at WHOI and other institutions for more than 20 years.

Waterbury, who worked closely with Watson for years, admired his ability to "approach scientific problems with an intuitive sense, not prejudiced by preconceived notions. He was quick to grasp the long-range implications of his observations." Another colleague and friend, Frederica Valois, who helped develop LAL, said Watson "hated to waste time that could be spent working, yet he balanced equal work with equal play."

In recognition of his leadership and generosity, WHOI will dedicate one of its new buildings as the Stanley W. Watson Laboratory.

—Kate Madin

A touchstone for marine chemists and students retires



Tom Kleindinst, WHOI

▲ **John Farrington presides over his last commencement as vice president for Academic Programs at WHOI in September. Farrington retired in November after 34 years at the Institution and 15 years leading the MIT/WHOI Joint Program.**

Passionate about science, education, and the welfare of his colleagues. A quiet champion for diversity—of gender, race, nationality, and intellectual approach—in oceanography. Colleagues and friends invoked such phrases to describe John Farrington, chemical oceanographer and longtime dean and vice president for Academic Programs at Woods Hole Oceanographic Institution. In November he stepped aside from his academic post after 15 years, and he will retire as a senior scientist in February after 34 years at the Institution.

During his tenure as dean, 366 students in the MIT/WHOI Joint Program in Oceanography were awarded graduate degrees, and the Institution recruited and hosted 198 postdoctoral fellows and 476 summer student fellows. Farrington became the first WHOI researcher to receive the B.H. Ketchum Award, given by colleagues to a scientist who demonstrates innovative approaches to coastal research, leadership in the scientific community, and attention to the effects of marine pollution on the coastal environment and society.

A native of New Bedford, Mass., Farrington joined WHOI in 1971 with a postdoctoral award in the laboratory of the pioneering organic geochemist Max Blumer. A one-year appointment turned into a full-time job, and he rose through the ranks of the Marine Chemistry and Geochemistry Department. Within 10 years, colleagues elevated him to the rank of senior scientist.

He established himself as a leader in the study of organic geochemistry in the ocean, conducting pioneering research on petroleum in the marine environment, on the mobility of contaminants such as polychlorinated biphenyls (PCBs) in seafloor sediments, and on the role of natural organic chemicals in the ocean. Along the way, he participated in 18 research cruises (eight as chief scientist), authored 117 refereed scientific papers, and contributed to more than 30 policy, education, or public information documents.

From 1981 to 1986 he served as the director of WHOI's Rinehart Coastal Research Center, but his leadership has extended well beyond Woods Hole. He has been a trustee of Bermuda Biological Station for Research since 1991, and he served on numerous national and international committees. For his service to the National Research Council, he was awarded the honorary title of national associate of the National Academy of Sciences.

Farrington became associate director for education and dean of graduate studies in 1990 and vice president for Academic Programs in 2002. During his tenure, Farrington led the effort to have WHOI's Academic Programs accredited, and he was a tireless advocate for students inside and outside the Institution, particularly for young women entering science. He is credited with expanding and strengthening the postdoctoral program.

"I have stayed at WHOI all these years because of my colleagues on the scientific and technical staff; the spirit of access to the sea; the employees who provide the support that enables scientists and engineers to carry out research ideas; the interactions with world-class students and postdocs; and the private support and advice of the trustees and corporators that enable freedom to pursue innovative ideas," Farrington said.

In celebration of his research, colleagues and protégés, led by Associate Scientist Chris Reddy and Assistant Scientist Liz Kujawinski, organized a Nov. 8 symposium on "Advances in Coastal Organic Biogeochemistry." It included James Quinn, emeritus professor from the University of Rhode Island and Farrington's mentor, and 10 speakers from as far away as Alaska and Japan.

"John's most important teaching occurred simply in the way that he lived his life," wrote Jeff Parkin, a one-time student in Farrington's lab who is now a middle school counselor. "He would always seem to make time for you, no matter how busy his schedule. He could find humor and patience in trying situations. He treated your most modest contribution as something significant, and he so deeply cared for his students."

—*Mike Carlowicz*

New dean brings experience from academe and federal agencies

The torch of leadership in WHOI's education programs was officially passed Nov. 28 to James Yoder, who becomes the sixth dean in the history of the Institution and its new vice president for Academic Programs. He was elected at the WHOI Board of Trustees meeting in mid-October.

Yoder comes to the Institution from the University of Rhode Island (URI), where he was a professor of oceanography. He used satellite sensors to study the relationship between physical and biological processes in the ocean. From 1993 to 1998 he served as associate dean of the URI Graduate School of Oceanography, where he had earned his own master's and doctoral degrees in the 1970s.

Between career stops at Skidaway Institute of Oceanography in Georgia and URI, he served as a visiting senior scientist at the Jet Propulsion Laboratory in California and also worked as a program manager in the oceans branch of NASA. From 2001 to 2004 he served as director of the Division of Ocean Sciences at the National Science Foundation.

"Jim brings a wealth of teaching and administrative experience in graduate education, as well as a unique perspective on the ocean research community," said WHOI President and Director Robert Gagosian. "He understands the federal funding system and the challenges facing ocean science from a number of viewpoints, and that insight will be helpful for students and researchers alike."


Tom Kleindinst, WHOI

▲ Jim Yoder, WHOI's new vice president of Academic Programs, held leadership posts at the National Science Foundation and the Univeristy of Rhode Island.

New fund established

Learning to use instruments to collect samples and to make measurements at sea is an essential part of an oceanographer's basic training. But finding ships and tools for practice is neither easy nor cheap. Graduate students often grab experience on the job, wherever and whenever they can.

To remedy this situation, two WHOI Associates helped establish the Edward and Erla Schwarm Family Fund before they died earlier this year. The fund provides ship time for students in the MIT/WHOI Joint Program to get hands-on instrument training aboard WHOI's research vessel *Tioga*.

"My father was an electrical engineer, a sailor, and a scientist," said Tom Schwarm, their son. Working at the MIT Instrumentation Laboratory, Ed Schwarm played a central role in developing the lunar module that landed the first men on the moon. He later built a successful electronics consulting business, Edward G. Schwarm Associates and earned 11 patents along the way.

The Schwarms lived on Cape Cod and were longtime WHOI Associates, regularly attending lectures at the Institution and participating in several WHOI-sponsored educational travel expeditions.

When Erla died in March 2005, Ed wanted to create a scholarship in memory of his wife of 62 years. "The idea of launching students on ship-based expeditions was something that pleased him," said Tom Schwarm. Ed died two months later, in May 2005.


Courtesy of Tom Schwarm

Erla and Ed Schwarm


Tom Kleindinst, WHOI

◄ MIT/WHOI graduate student Mike Braun gets his Ph.D. diploma—and a kiss from mom.

Bon voyage, Class of '05

In September, 22 students of the MIT/WHOI Joint Program in Oceanography and Applied Ocean Science and Engineering gathered for commencement ceremonies in Woods Hole as part of the Institution's 75th anniversary celebration. Activities began with a daylong symposium on the oceans and education; later, Patricio Bernal, executive secretary of the Intergovernmental Oceanographic Commission and assistant director-general of the United Nations Educational, Scientific and Cultural Organization, delivered the commencement address. In all, 25 doctorate and nine master's degrees were awarded for the 2004-2005 academic year. Since the program began in 1968, the program has awarded 722 degrees. WHOI last hosted a Joint Program graduation in June 2000; the next is planned for 2010.

Sarah Das

Tracking an ocean of ice atop Greenland

Sarah Das calls herself a "frozen oceanographer." Most people look at Greenland and see a vast ice sheet covering Earth's largest island. But Das sees a huge reservoir of water—temporarily removed from the ocean and solidified on land. The Greenland Ice Sheet is the second-largest concentration (after Antarctica) of fresh water on Earth; if it melted completely, global sea levels could rise up to 7 meters (23 feet).

In recent years, evidence has mounted that global warming may be accelerating the melting of land ice and sea ice in the Arctic. That melting would amplify warming even further, because while the white surfaces of ice reflect most incoming solar radiation back to space, darker ocean and land surfaces absorb it. In addition, enhanced ice melting could contribute a big slug of fresh water to the North Atlantic Ocean, which could potentially alter its circulation and cause dramatic regional and global climate change.

The surprise is that these changes in warming and melting may not be happening gradually, but quickly. The ice sheet may be responding to climate change in ways that scientists hadn't anticipated. The reason, Das explains, is that ice sheets behave less like slowly thawing ice cubes, and more like pancake batter.

Pancake batter?

When you pour pancake batter in a griddle, it spreads out under its own weight. Ice does that, too. It flows downhill—eventually to the ice sheet's outer margins, where it drains into the sea.

We've thought that the Greenland Ice Sheet, for the most part, moves and reacts slowly to climate changes. But from 1997 to 2003, the speed of Jakobshavn Glacier on Greenland's west coast has doubled. Jakobshavn is the largest outlet glacier in Greenland and drains 6.5 percent of the entire ice sheet. On the east coast, the Kangerdlugssuaq Glacier, which drains 4 percent of the ice sheet, has also sped up in the last decade, from 5 kilometers (2.25 miles) to 14 kilometers (6.4 miles) per year.

Things are happening much faster than we ever thought possible. It shows that we don't completely understand how ice sheets work and how they are responding to climate change.

What is making the ice sheets less monolithic and more mobile?

One thing that really controls the speed of a glacier is what is happening at the bed—where the land meets the bottom of the glacier. Conventional wisdom tells us that any warming near the ice sheet's surface should take thousands of years to penetrate 1 to 2 kilometers of cold ice. Temperatures are near the freezing point at the bed, so the ice is colder there, and less water is available for lubrication. That creates friction. Anything that reduces friction between the ice and the ground, such as adding water, makes the ice sheet flow faster.

Does that mean the glacial beds are getting lubricated?

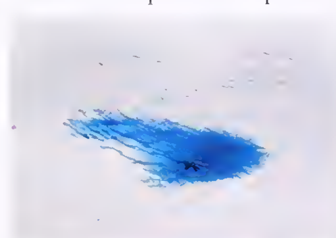
Our hypothesis is that there may be a connection between more melting on the surface and more water reaching the bed—controlled by the behavior of features called supraglacial lakes. Each summer around the margins of the Greenland Ice Sheet, surface ice melts and pools in low spots to form lakes, some many kilometers across. The lakes drain throughout the season through cracks in the ice, and when there is more melting, the glaciers appear to speed up. The lakes may concentrate water so that it causes the ice to fracture and water to be injected directly to the bed. That could really change the dynamics of the entire ice sheet.

How can water create such large cracks?

That is one of the big unknowns. I've been collaborating with another scientist in the WHOI Geology and Geophysics Department, Mark Behn, who studies rock fractures and magma propagation in the seafloor. We just received a WHOI interdisciplinary study award to see if the physics of his models for the seafloor can apply to ice sheets—to see, for example, what happens if you have a large enough pool of water that you drive down a small crack under the pressure and temperature conditions seen on the ice sheet. Will the ice fracture down to the bed?

Are more supraglacial lakes forming because of global warming?

We don't know yet. We've just been funded by the National Science Foundation to look at several decades of high-resolution satellite data that provide snapshots of what's happening on the ice sheet surface. We can look at how the distribution of lakes changes from year to year and correlate that with climate records from weather stations to determine whether warmer temperatures created more, or bigger, lakes. We can also look at how the lakes drained to understand when and why some lakes drain and some don't.


Sarah Das, WHOI

▲ Supraglacial lakes, several kilometers long, form in summer from melted ice atop the Greenland Ice Sheet.

We're also going to several representative lakes next summer. From the Greenland coast, a helicopter will take our team, tents, emergency equipment, and scientific gear about 100 kilometers up the ice, drop us off for a few weeks to work, and move us between field sites. We will put out instruments to measure how fast the ice is moving and to record lake levels and temperatures. We'll also deploy some seismometers that can record seismic waves caused by any ice fracturing under the lake.

What is life on the ice like?

Being on an ice sheet sort of feels like being at sea, only everywhere you look it's ice instead of ocean. There is sunlight 24 hours a day. The sun doesn't really go up or down, it just goes around and around and around. There are subtle variations in how high and

how warm it is at different times of day, but you really have to pay attention to notice that. And you are living in the cold, day in and day out. Many times, there isn't a place you can go to warm up.

You are really isolated and depend on your co-workers. Everyone does everything that needs to be done. You don't have the hierarchy you have in the rest of your life.

How did you get into this line of work?

I spent summers with my grandparents on Cape Cod. It was the best time of year for me. I fell in love with oceans and said I was going to be an oceanographer. I majored in geology in college and did a semester at sea aboard SSV *Westward*, Sea Education Association's ship, on a research cruise out of Woods Hole.

Then someone told me about a summer field course in Alaska. We went up there with our backpacks, our skis, and our senses of humor and traversed the Juneau Ice Field, stopping at huts along the way, doing science, learning how to rescue ourselves from crevasses, climbing mountains, telemark skiing. Man, that was even more exciting than oceanography.

My first job after college was as a field technician with a Cal Tech research group. They needed someone willing to leave routine life for three months and live out of a tent in Antarctica. We drilled boreholes to collect samples and study conditions beneath the ice.

Beyond the adventure, I became amazed and impressed by how important ice sheets are. They are critical to the climate system and sea level. And they aren't just big blocks of ice; they are also archives of Earth's climate history.

Near their summits, where the ice sheets don't melt much, every year's snowfall is stacked up and preserved—like annual tree rings. You can drill a core through the ice, analyze ice samples, and get a record of climate back through the ice ages and the warm periods between ice ages. In November, a new study, using gas bubbles trapped in ice 3 kilometers below Antarctica's surface, reported that current levels of greenhouse gases in Earth's atmosphere are higher now than at any time in the past 650,000 years.

What do you do when you're not doing scientific work?

My husband and I bought a sailboat cheap and fixed it up, and we sail in Boston Harbor. This summer I raced in the first annual Boston Harbor Islands Regatta in a special class for female skippers, and I took second place. I do a lot of hiking, biking, skiing, kayaking, gardening—anything that gets me outdoors. For the last few years, I have also enjoyed doing triathlons.

Does that training come in handy on the job?

Absolutely. When I take my lunch break and go for a run I think, "Well, this is for work." When you're dropped off by a plane at 10,000 feet, and you have to set up camp, drill an ice core, and make dinner in three hours, you need to be in great shape.

—Lonny Lippsett

Andrew Kurtz

▲ Sarah Das, assistant scientist, Department of Geology and Geophysics

"I became amazed and impressed by how important ice sheets are. They are critical to the climate system and sea level. And they aren't just big blocks of ice; they are also archives of Earth's climate history."

Big whale, big stink

A finback whale found floating southeast of Nantucket in September stretched as long as WHOI's 18-meter (60-foot) research vessel *Tioga*. To learn why the animal died, scientists performed a partial necropsy at sea. Read more on page 5.

Tim Voorheis, Gulf of Maine Productions

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